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**THE ARCHEAN GEOLOGY OF THE  
GODTHÅBSFJORD REGION,  
SOUTHERN WEST GREENLAND**

**(Includes Excursion Guide)**

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## INTRODUCTION

[ This account is concerned with the part of the West Greenland Archean gneiss complex centered around Godthåbsfjord and extending from Isukasia in the north to south of Færingehavn. ] The special significance of this region for understanding crustal genesis in the early history of the Earth includes the following.

(1) Extensive outcrops of 3800–3400 Ma rocks can provide some direct evidence of conditions and processes that operated on the Earth in the early Archean. However, the ways in which primary characteristics have been modified by later deformation, metamorphism, and chemical changes must first be taken into account.

(2) The rocks exposed are the products of two major phases of accretion of continental crust, at 3800–3700 Ma and 3100–2900 Ma. The main features of these two accretion phases are similar, but careful study of the least modified rocks may reveal differences related to changes in the Earth in the intervening period.

(3) The combination of excellent exposure over an extensive area, relatively detailed geological mapping of much of the region, and a considerable volume of isotopic and other geochemical data gives special insight into processes that operated at moderately deep levels of the crust in the Archean. Of particular interest is the effect of late Archean granulite facies metamorphism on early Archean rocks, especially the extent to which isotope systems were disturbed. Similar processes may well have partly or wholly destroyed evidence of more ancient components of other high grade terrains.

Stratigraphic relations and the first-order elements of the chronology were first worked out during the late 1960s, mainly within the area of the Qôrqt 1:100,000 geological map sheet (64 V 1 S). Field mapping of this sheet extended from 1965 to 1979 and much of it was of a reconnaissance nature only, based on coastal outcrops and rather widely spaced traverses inland. Part of the Nordlandet peninsula, the Qôrqt granite complex between Qôrqt and Sulugssugutip kangerdlua, the peninsulas and islands between the mouths of Godthåbsfjord and Ameralik, and some areas on the south side of Ameralik were mapped in greater detail.

The Buksefjorden 1:100,000 map sheet (63 V 1 N) to the south was mapped in considerable detail between 1972 and 1977 (*Chadwick and Coe*, 1983). Most of the sheet was mapped on a scale of 1:20,000, while the Narssaq peninsula and the islands around Qilângårssuit were mapped at 1:10,000. Our field studies and those of *Sharpe* (1975) show that the full extent of early Archean rocks is not shown on the Buksefjorden map sheet.

Field mapping for the Ivisârtoq (64 V 2 N) and Isukasia (65 V 2 S) 1:100,000 map sheets in the northeastern part of the region was carried out from 1981 to 1983. Mapping was less detailed than for the Buksefjorden sheet but benefited from advances in understanding of the regional geology that had been made in the 1970s. Both sheets are in the process of compilation and drafting. Mapping is in progress for the Fiskefjord 1:100,000 map sheet (64 V 1 N) north of the Qôrqt sheet. The Isua supracrustal belt and adjacent gneisses have been mapped in considerable detail by G.G.U. geologists and will be published at 1:40,000.

The Frederikshåb Isblink-Søndre Strømfjord 1:500,000 geological map sheet is based on the 1:100,000 map sheets for the whole of the area south of 64°N and for the area of the Qôrqt sheet. The remainder of the map area was compiled from helicopter and coastal reconnaissance in 1976–1978. It does not include the results of mapping for the Ivisârtoq, Isukasia, and Fiskefjord 1:100,000 sheets. No further regional mapping has been done since helicopter reconnaissance in 1976 within the Kapisigdlit 1:100,000 map sheet area (64 V 2 S), east of the Qôrqt sheet. The geology of this part of the region is relatively poorly known.

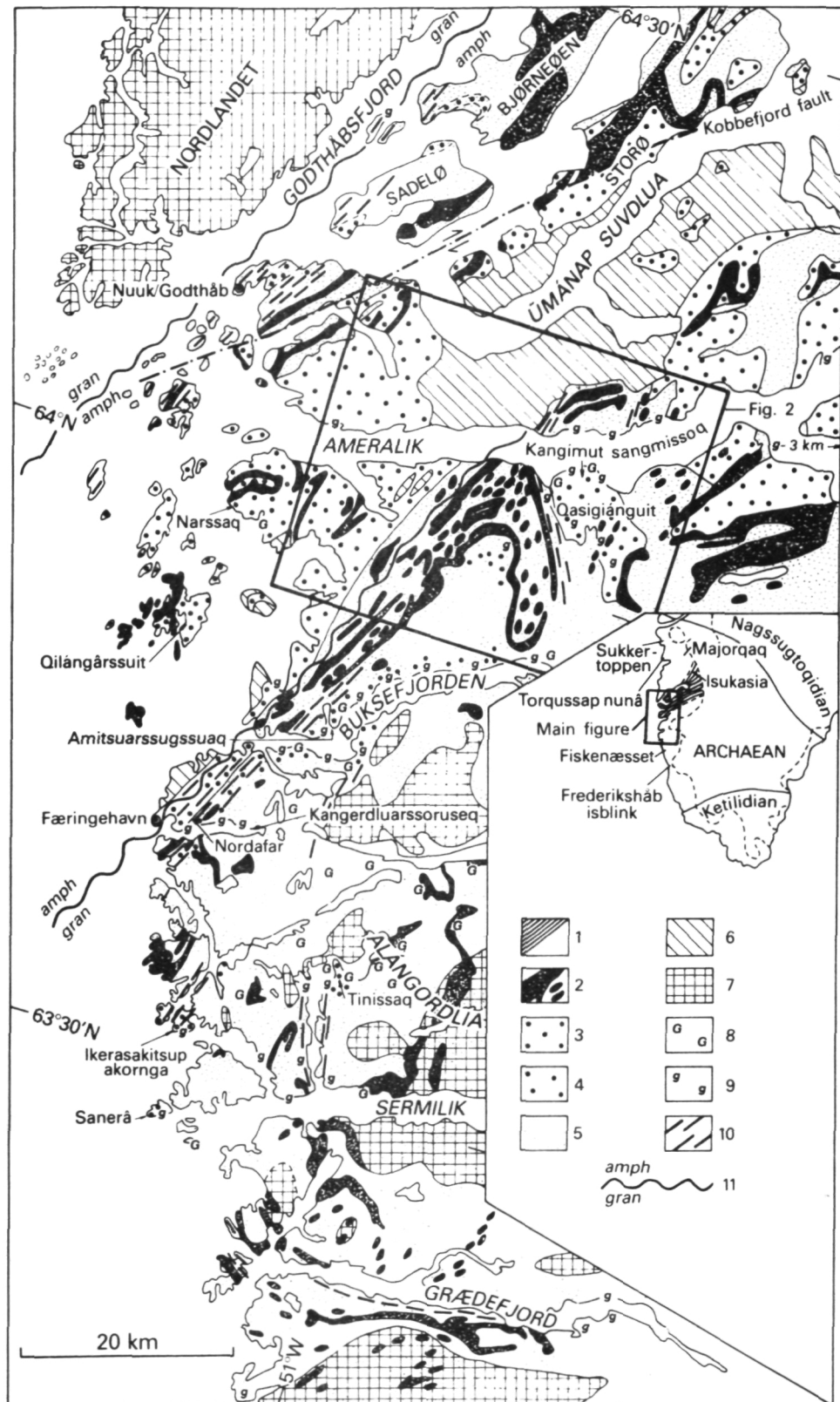
It is recommended that the reader acquire the 1:100,000 Qôrqt (64 V 1 S) and Buksefjorden (63 V 1 N) and 1:500,000 Frederikshåb Isblink-Søndre Strømfjord geological map sheets in order to follow the description of the geology that follows. These map sheets can be ordered from the Geological Survey of Greenland, Øster volgade 10, DK-1350 Copenhagen K, Denmark. The price per sheet in 1985 was 100 Danish kroner, exclusive of mailing charges.

[ This account does not attempt to be an exhaustive review of all work carried out on the geology of the region. Rather, it attempts to summarize aspects of the geology and some recent speculations on its significance that can be of interest in the context of early crustal genesis. ] Earlier papers and ideas are referred to only where they have not been superseded by later work. The geology of the Godthåbsfjord region is extremely complex and still far from properly understood. We apologize if the reader becomes lost at times in the details of what follows. We often get lost ourselves.

## EARLY ARCHEAN

An older complex of rocks in the Godthåbsfjord region was separated from younger rocks initially on the basis of a single field criterion: that they contain very abundant tabular bodies of amphibolite derived from basic dikes to which the name Ameralik dikes was given (*McGregor*, 1973). Amphibolites derived from basic





dikes are rare or absent in other lithologic units in the region, and these units were presumed to be younger than the Ameralik dikes. Subsequent isotopic studies showed that the units with abundant Ameralik dikes or, in the Isukasia area, cut by less deformed Tarssartôq dikes, which are at least in part equivalent to the Ameralik dikes, were all formed between about 3800 and 3400 Ma (references elsewhere in this volume).

Early Archean rocks, intercalated with younger rocks, have been recognized with certainty within a tract that extends for 200 km from the margin of the Inland Ice at Isukasia to the outer coast south of Faeringhavn. To the southeast, early Archean units are disrupted by increasing amounts of mid- to late Archean gneisses, and they become more difficult to recognize because of more intense late Archean modification. In particular, late Archean granulite facies metamorphism partly erased field evidence for separating early Archean gneisses from younger rocks and destroyed the early Archean isotopic signature (see below). Early Archean rocks extend farther south and southeast than is indicated on the 1:500,000 and the Buksefjorden 1:100,000 map sheets. Rocks that we consider on the basis of field criteria to be early Archean crop out to within 4 km of the head of Buksefjorden and south as far as Tinissaq (*Chadwick et al.*, 1974) and the islands at the mouth of Sermilik (Figure 1). Here they make up only a relatively small proportion of the geology.

Early Archean rocks may be present locally northwest of the Godthåbsfjord region. *Hall* (1977, 1985) noted banded iron formation and other lithologies that suggest early Archean rocks near the margin of the Inland Ice 80 km NNE of Isukasia. Rocks that resemble Amitsoq gneisses and Ameralik dikes form part of Tovqussap nunâ, north of the mouth of Fiskefjord.

Early Archean rocks in northern Labrador (see *Collerson et al.*, 1982, for references) resemble the early Archean rocks in the southern part of the Godthåbsfjord region, and they probably formed parts of the same complex before the opening of the Labrador sea.

In West Greenland the early Archean rocks are best preserved in the Isukasia area, which is described separately (*Nutman and Rosing*, this volume). Throughout the remainder of the tract where they have been recognized, their primary characters have been severely modified by mid- to late-Archean plutonic activity: intense deformation, intrusion of voluminous granitoid magmas, and high-grade metamorphism. The early Archean rocks in the Godthåbsfjord region outside the Isukasia area comprise the *Akilia association* of supracrustal and basic to ultrabasic intrusive rocks and the younger and much more voluminous *Amitsoq gneisses* that intrude them.

## AKILIA ASSOCIATION

Fragments of older rocks occur throughout the region within the Amitsoq gneisses. Except for the rocks of the Isua supracrustal belt, they are all grouped for convenience under the term Akilia association (*McGregor and Mason*, 1977). The range of Akilia lithologies is similar throughout the region and there are similarities with especially the lowest part of the Isua supracrustal sequence. There is no indication that rocks of more than one age group are involved. It seems most probable that the Isua supracrustal belt and all of the Akilia supracrustal rocks are parts of a single sequence that was "exploded" by intrusion of the parents of the Amitsoq gneisses.

Individual bodies of Akilia rocks range in size from very small up to mappable units hundreds of meters thick that can be followed for kilometers. Especially extensive units crop out northeast of Qôrqt and between the Isukasia area and the head of Godthåbsfjord.

*Nutman* (1980) grouped Akilia rocks SSW of the mouth of Ameralik into (1) an early assemblage of interlayered amphibolites, banded iron formations, and felsic gneisses of probably volcanic and sedimentary origin; (2) massive leucogabbroic rocks intrusive into (1); and (3) layered ultramafic rocks.

Fig. 1. Geological sketchmap of the southern part of the Godthåbsfjord region and the northern part of the Fiske-næsset region; (1) Belt of rocks not affected by granulite facies metamorphism in the late Archean; (2) Mid-Archean supracrustal and anorthositic rocks; (3) Early Archean rocks, mainly Amitsoq gneisses; (4) Areas with early Archean rocks extensively intruded by mid- to late Archean gneisses; (5) mid- to late Archean gneisses (Nûk gneisses and equivalents); (6) Qôrqt granite complex; (7) Areas with granulite facies mineral assemblages; (8) Localities with mineralogical evidence (relic orthopyroxene) of late Archean granulite facies metamorphism in rocks mainly retrogressed to amphibolite facies; (9) Localities with textural evidence of late Archean granulite facies metamorphism in retrogressed rocks; (10) Post-granulite facies deformation belts; (11) Approximate position of original late Archean prograde granulite-amphibolite facies boundaries.

Rapid variations occur within the rocks of group (1), which is dominated by basic lithologies. These comprise layered mesocratic amphibolites with Fe-rich tholeiitic affinities and rocks that range from pyroxene-bearing amphibolites to clinopyroxenites. The pyroxene-bearing layered basic rocks have high MgO, Cr, and Ni and low  $\text{Al}_2\text{O}_3$ ,  $\text{TiO}_2$ , and  $\text{Na}_2\text{O}$ . *McGregor and Mason* (1977) concluded that they were chemically comparable to the komatiitic association but considered it possible that at least some were of cumulate origin. No primary igneous textures are preserved in them. *Nutman et al.* (in preparation) question whether any of these rocks crystallized from komatiitic liquids and suggest that all or most of them are derived from tholeiitic magmas in which olivine and orthopyroxene had accumulated.

The metasedimentary rocks are mostly quartz-rich pyroxene-, amphibole-, magnetite-, and garnet-bearing rocks in which graphite, biotite, molybdenite, and carbonate occur locally. They are interpreted as derived from varieties of banded iron formation with possible associated chert. Less common are rusty-weathering biotite-garnet-feldspar gneisses, locally associated with quartz-rich gneisses, that are thought to be derived from acid to intermediate volcanics or from feldspathic detrital sediments. Some quartz-rich layered rocks appear to be the result of secondary introduction of silica.

The leucogabbroic rocks of group (2) form sheets intruded into the volcanic-sedimentary sequence. Locally there is poorly developed layering interpreted as of primary igneous origin, for example, on SE Qilángårssuit where this unit contains anorthositic layers. The composition of fine-grained homogeneous varieties may to a first approximation be that of liquids and resembles strongly fractionated "komatiitic" liquid compositions.

The ultramafic rocks (3) are mainly meta-peridotites. Olivine has been partly or completely hydrated and occurs as relics associated with pyroxene, tremolitic amphibole, talc, serpentine, and phlogopite. These rocks are interpreted as derived from cumulate facies of the layered basic rocks.

Extensive units of Akilia association rocks between the mouth of Ameralik and the head of Godthåbsfjord have not been studied in any detail and could well repay investigation.

## AMÏTSOQ GNEISSES

This term is used for all quartzofeldspathic gneisses in the Godthåbsfjord region that contain abundant amphibolites derived from basic dikes or that, in the Isukasia area, are cut by Tarssartôq dikes. Wherever these rocks have been studied isotopically between Storø, in Godthåbsfjord, and the islands northwest of the mouth

of Buksefjorden, as well as in the Isukasia area (references in *Nutman and Rosing*, this volume), they have yielded early Archean ages by Pb/Pb and Rb/Sr whole rock isochron methods (*Black et al.*, 1971; *Moorbath et al.*, 1972; *Griffin et al.*, 1980) and by U/Pb and Th/Pb zircon methods (*Baadsgaard*, 1973). Sample suites used in the earlier isotopic studies were collected before the polygenetic nature of the Amîtsoq gneisses was investigated in detail. Later studies of better preserved rocks from the Isukasia area (*Baadsgaard*, 1983, and unpublished data), show that the various phases that make up the Amîtsoq gneisses were intruded episodically over a period between 3750 and 3400 Ma. The approximate Rb/Sr and Pb/Pb whole rock isochrons obtained from the mixed suites collected in the late 1960s and early 1970s are probably to a considerable extent the result of high-grade metamorphism, reaching granulite facies grade in the south, that affected most of the Amîtsoq gneisses ca. 3600 Ma ago (*Griffin et al.*, 1980).

Most of the Amîtsoq gneisses are highly deformed, layered grey gneisses, commonly with abundant thin pegmatitic layers. Layered gneisses of this type are seen in the Isukasia area to be the products of intense deformation of polyphase parents that include an early tonalitic suite intruded 3750–3700 Ma ago, a granitic suite intruded into the tonalitic gneisses at ca. 3600 Ma, and minor pegmatitic sheets emplaced around 3400 Ma (*Nutman and Rosing*, this volume). The intense deformation erased original discordant contacts between the different phases and smeared out individual bodies into thin concordant layers. In many places it was accompanied by metamorphic differentiation and segregation of pegmatitic material into discrete thin layers. Thus most of the Amîtsoq grey gneisses outside the least deformed part of the Isukasia area have lost almost all of their primary characters. Homogeneous phases that preserve some primary characters do occur locally outside the Isukasia area in small areas of low strain.

South of the mouth of Ameralik, a geochemically distinct iron-rich suite of augen and ferrodioritic gneisses makes up ~ 30% of the Amîtsoq gneisses (*Nutman et al.*, 1984). These rocks are generally more homogeneous and preserve more primary features than grey gneisses in the same area. Contacts between them and the grey gneisses are everywhere concordant, but several lines of evidence suggest that the iron-rich suite was intruded as sheets into the layered grey gneisses.

The ferrodioritic gneisses occur as strips within the augen gneisses. Locally they grade into augen gneisses over several tens of meters, but elsewhere they form sharply bounded inclusions within them. The two

lithologies are interpreted as having been emplaced more or less contemporaneously. The augen gneisses form sheets up to 200 m thick that can be traced for as much as 15 km. Their composition ranges from dioritic to granitic with potassic granodiorite most abundant. Granodioritic and granitic varieties contain abundant augen derived from microcline megacrysts. In the least deformed rocks these megacrysts are up to 2 cm long and may be randomly oriented. Compositional layering is interpreted as deformed igneous layering.

Geochemical studies suggest that the parents of the augen gneisses were the products of mixing of granodioritic melts of deep crustal origin with fractionated basic melts of mantle origin. The ferrodiorites are interpreted as strongly fractionated, crystallized parts of basic intrusions that were carried up to higher crustal levels within the heterogeneous plutons. The Amîtsoq iron-rich suite resembles post-orogenic granitic complexes from younger epochs such as the mid-Proterozoic rapakivi granite suites.

Homogeneous tonalitic gneisses that appear to be younger than the layered grey gneisses form discrete mappable bodies on some islands south of the mouth of Ameralik. Their relations to the iron-rich suite are not known. Sheets of trondhjemitic and granitic gneiss up to 20 m thick cut rocks of the iron-rich suite and adjacent layered grey gneisses. They are only a very minor component of the Amîtsoq complex and are interpreted as crustal melts of local origin.

### EARLY ARCHEAN GRANULITE FACIES METAMORPHISM

Granulite facies mineral assemblages are preserved very locally within rocks of the Akilia association and the Amîtsoq iron-rich suite on islands northwest of the mouth of Buksefjorden (Griffin *et al.*, 1980). We have found relic textures that we consider to have formed under granulite facies conditions in Amîtsoq gneisses and inclusions in them between the Teltørne, just south of Færingehavn, and Qôrqt in Godthåbsfjord. All of these localities are outside the terrain affected by granulite facies metamorphism in the late Archean (see below). There is no evidence of granulite facies metamorphism in intercalated Malene supracrustal rocks.

Mafic augen gneisses with partly retrogressed granulite facies mineral assemblages from a small island west of the mouth of Buksefjorden give well-fitted Rb/Sr and Pb/Pb whole rock isochrons that yield dates of  $3560 \pm 140$  Ma and  $3625^{+125}_{-135}$  Ma, respectively (Griffin *et al.*, 1980). This shows that the granulite facies metamorphism occurred no later than ca. 3600 Ma ago, since granulite

facies metamorphism is normally accompanied by movement of U and Rb. Zircons from Akilia association rocks affected by early granulite facies metamorphism from a number of localities yield a concordia intersection age of  $3587 \pm 38$  Ma, while zircons from the Isua supracrustal belt yield a concordia intersection age of  $3813^{+24}_{-14}$  Ma (Baadsgaard *et al.*, 1984). There is no reason to believe that the Akilia rocks are younger than those of the Isua supracrustal belt, and the Akilia intercept age is considered to be the result of resetting of the zircons by the early granulite facies metamorphism. Zircons from Amîtsoq gneisses affected by early granulite facies metamorphism from localities south of the mouth of Ameralik yield U-Pb and Th/Pb concordia intercept ages of  $3600 \pm 50$  Ma and  $3550 \pm 85$  Ma, respectively (Baadsgaard, 1973; recalculated with new constants by Baadsgaard *et al.*, 1976). Four of the six samples were from the iron-rich suite, one was from a late sheet cutting augen gneiss and one was from a late homogeneous tonalite. A Lu/Hf age of  $3550 \pm 220$  Ma was reported by Pettingill and Patchett (1981) for a collection of Amîtsoq gneiss samples belonging almost entirely to the iron-rich suite and closely associated late phases.

Intrusive suites that are chemically similar to the Amîtsoq iron-rich suite are commonly closely associated in time and space with granulite facies metamorphism, for example the 2800 Ma Ilivertalik augen granite suite in the Fiskenaeset region to the south (see below). The Amîtsoq iron-rich suite is restricted to areas affected by the ca. 3600 Ma granulite facies metamorphism and it is likely that the two phenomena were connected.

By 3600 Ma the continental crust of which the early Archean rocks in this region formed a part was at least 20 km thick, had a geothermal gradient of  $30^\circ\text{C}/\text{km}$  (Griffin *et al.*, 1980) and had developed a chemical stratification through anatexis and movement of granitic magmas to higher crustal levels. This early Archean sial thus had many features in common with sialic crust that stabilized later in the Earth's history, particularly toward the end of the Archean.

### AMERALIK DIKES

This term is used for the abundant tabular bodies of massive, homogeneous amphibolite derived from basic dikes that occur within early Archean rocks in the Godthåbsfjord region. Less deformed, unbroken basic dikes, at least in part equivalent to the Ameralik dikes, that cut early Archean rocks in the Isukasia area are termed Tarssartôq dikes (Nutman *et al.*, 1983).

Ameralik dikes occur every few meters or tens of meters across the strike in most outcrops of early



Archean rocks outside the Isukasia area. Tarssartôq dikes in the least deformed parts of the Isukasia area are much more widely spaced. This probably reflects telescoping of the rocks by more intense deformation outside the Isukasia area. Most Ameralik dikes are less than 2 m thick, while Tarssartôq dikes are commonly 20–100 m thick. The contacts of most Ameralik dikes have been rotated by intense deformation into concordance with the layering of the enclosing rocks. Most Ameralik dikes are strongly folded and broken up.

There is no compelling reason to believe that the Ameralik dikes are all genetically related or that they were intruded within a relatively short period of time. *Chadwick* (1981) grouped Ameralik dikes between the mouths of Buksefjorden and Ameralik into a number of different types on the basis of field and petrographic characters. A small proportion of Ameralik dikes, shown by rare intersections to be among the older dikes, contain white plagioclase clots that in some of the least modified dikes are seen to be derived from euhedral megacrysts of calcic plagioclase. The plagioclase clots are commonly concentrated in trains nearer one margin of the dikes, suggesting flotation in nonvertical bodies (*Nutman*, 1980). We have not observed comparable plagioclase clots in any other basic lithology in the region and have found them to be a particularly useful indicator of highly modified Ameralik dikes and thus of early Archean units. *Chadwick et al.* (1983) reported plagioclase aggregates in a small number of metamorphosed basic dikes in the Ivisârtoq area that they considered to be younger than Ameralik dikes. We are, however, skeptical about their interpretation of the field relations.

The chemistry of Ameralik dikes between the mouths of Buksefjorden and Ameralik was studied by *Chadwick* (1981) and that of a compositionally more restricted collection of Ameralik dikes, including Tarssartôq dikes, from the whole region by *Gill and Bridgwater* (1976, 1979). Most of the dikes have low-K tholeiitic affinity but are commonly iron-rich. However, ultramafic dikes also occur (*Chadwick*, 1981; *Gill et al.*, unpublished data).

The Ameralik dikes cut rocks that 3600 Ma ago formed part of a body of sialic crust with typical continental thickness. *Gill and Bridgwater* (1979) pointed out that there were no recent examples of low-K tholeiitic magmas intruded into the interior of a large sialic crustal segment, except where there was rifting in the initial stages of sea-floor spreading. The Ameralik dikes were intruded after ca. 3400 Ma (the age of Isukasia area Amitsoq pegmatites) but before intrusion of the first Nûk gneisses ca. 3100 Ma ago. They may well have been intruded toward the end of this period, after the

continental mass that included the Amitsoq gneisses had been thinned tectonically and by erosion, near what subsequently became the rifted margin of a continent.

## MALENE SUPRACRUSTAL ROCKS

This term is used for all mid-Archean supracrustal rocks (formed at the surface, i.e., of sedimentary or volcanic origin) in the Godthåbsfjord region.

### 1. Stratigraphic Relations

It was originally thought that Malene supracrustal rocks were not cut by basic dikes like the Ameralik dikes (*McGregor*, 1973). Metamorphosed basic dikes have subsequently been found cutting some Malene lithologies, although they are not nearly as abundant as Ameralik dikes within the early Archean rocks (*Chadwick*, 1981; *Friend and Hall*, 1977). The apparent scarcity of amphibolites derived from basic dikes within the basic Malene units may be more apparent than real, since deformation and metamorphism would have transformed most basic dikes into thin, concordant layers of homogeneous amphibolite. Amphibolites derived from basic dikes are absent or rare in most Malene metasedimentary units.

The chemical similarity of basic dikes cutting Malene supracrustal rocks and of homogeneous Malene amphibolites to the most common types of Ameralik dikes has been considered to support the idea that at least some of the Ameralik dikes were feeders to the lower, basic part of a Malene sequence laid down on a basement of Amitsoq gneisses (*Chadwick*, 1981; *Nutman and Bridgwater*, 1983). However, these chemical similarities are common to the majority of Archean basic rocks in other terrains and other situations, including many greenstone belts (*Gill*, 1979; *Gill and Bridgwater*, 1979).

Malene supracrustal units enclosed in Amitsoq gneisses are very extensive, even where they are quite thin. Contacts with Amitsoq gneisses that are not modified by the intrusion along them of Nûk gneisses, pegmatites, etc. are generally concordant and sharp. At least some Malene-Amitsoq contacts are modified thrusts, since Malene lithologies are cut out when followed along them (*Chadwick and Nutman*, 1979), and successive Malene units within the composite Malene-Amitsoq pile have different lithological associations (*McGregor*, 1975). Northeast of Godthåbsfjord, Malene amphibolites in which the way-up is indicated in places by little-deformed pillow-lava structures are overlain stratigraphically by Amitsoq gneisses (*Hall and Friend*, 1979; *Chadwick*, 1985). One

of the contacts between these two units must therefore be a thrust, yet there is no mylonitization or brecciation and S fabrics are no more intense than in the gneisses and Malene rocks distant from the contact. In places there is a thin layer of biotite schist with quartz nodules along the contact.

*Chadwick and Nutman* (1979) and *Nutman and Bridgwater* (1983) have argued that certain contacts between Malene and Amîtsoq units on the islands between the mouths of Ameralik and Buksefjorden are parts of a deformed unconformity. This is based on the following: (a) The presence of thin units of brown, micaceous gneiss and quartz-rich lithologies between Malene amphibolites and Amîtsoq gneisses. These can be followed for hundreds of meters along parts of the contact and are interpreted as being derived from basal sediments (arkoses, detrital quartzites, and cherts) that were deposited on a basement of Amîtsoq gneisses. (b) Lack of veining, intense shearing, mylonitization, or interdigitation along the generally sharp contact. (c) Several lines of evidence that suggest that the Malene amphibolites lie stratigraphically below the Al-rich paragneisses that are the other major component of the Malene unit on the southern islands. (d) Local truncation of migmatitic veins in Amîtsoq gneisses by sharp contacts to Malene amphibolites. This evidence is compatible with the interpretation that these Malene units were laid down as a cover sequence on a basement of Amîtsoq gneisses, but it does not prove it. It remains a possibility that all Malene-Amîtsoq contacts are thrusts.

Malene paragneisses on Rypeø have REE patterns and abundances (*Dymek et al.*, 1983; *McLennan et al.*, 1984) that suggest derivation from rocks like the tonalitic gneisses that are the dominant lithology in both the Amîtsoq gneisses (*O'Nions and Pankhurst*, 1974; *Nutman et al.*, 1984) and the type Nûk gneisses (*J. G. Arth*, unpublished data). Sm/Nd characteristics of two samples of the Rypeø paragneisses do not indicate contributions to the parent sediments from early Archean rocks (*Hamilton et al.*, 1983). As yet unpublished ion probe studies at Cambridge University have identified early Archean zircons in Malene paragneisses, but indicate that the provenance of the sediments also included contemporaneous (felsic?) igneous rocks.

## 2. Lithologies

(a) *Amphibolites* are the most abundant lithology. Deformation has been so intense in most places that primary structures have been destroyed or modified beyond recognition. Pillow structures are preserved on Ivisârtoq both in amphibolites and in subordinate, but intimately associated ultramafic horizons (*Hall*, 1980,

1981). Here, as elsewhere in the West Greenland Archean (e.g., *Myers*, 1978), intense deformation of basic pillow lavas and associated pillow lava breccias and agglomerates produced finely layered ("striped") amphibolites such as those that make up about half of the Malene amphibolites in other areas. A common variety of striped amphibolite has discontinuous layers and lenses that contain varying proportions of hornblende, diopside, and epidote in addition to plagioclase, and locally also garnet, scapolite, and carbonate. In the Ravns Storø supracrustal belt in the southern part of the Fiskenaeset region similar rocks can be followed into pillow lavas in which the pillow centers have been altered to Ca-rich compositions (*Friend*, 1975). Larger bodies of calc-silicate-rich (skarn) lithologies occur locally within Malene amphibolite units. For example, layers of diopside-scapolite-epidote-sphene rocks are common in the Malene unit at Narssaq south of the mouth of Ameralik. It is reasonable to assume that the striped Malene amphibolites are mainly derived from basic volcanic parents, many or all of which were erupted under water.

Concordant sheets of homogeneous amphibolite, some rich in garnet, that are interlayered with the striped amphibolites are assumed to be derived from thick basic flows, sills, or dikes that have been rotated into concordance by deformation.

*Hall* (1980, 1981) found a continuum in the chemistry of the pillowed Malene rocks on Ivisârtoq from tholeiitic to basaltic and pyroxenitic komatiite compositions, while *Chadwick* (1981) reported low-K tholeiitic chemistry for homogeneous Malene amphibolites between the mouths of Buksefjorden and Ameralik.

(b) *Ultramafic rocks* occur as sheets and pods within Malene amphibolite units and along the contacts of some units with Amîtsoq gneisses. They are most extensive west of the thick Malene unit on Sadelø and Bjørnøen in Godthåbsfjord where this unit is intruded by Nûk gneisses.

(c) *Quartz-garnet-sillimanite and quartz-cordierite-anthophyllite gneisses* form what is interpreted as the stratigraphically higher part of the Malene unit on the islands northwest of the mouth of Buksefjorden (*Beech and Chadwick*, 1980). Quartz-garnet-sillimanite gneisses associated with thin, nonpersistent units of marble, green mica gneiss and gedrite-magnetite rock overlie Malene amphibolites and locally contain structures interpreted as cross-bedding. They are in turn overlain by quartz-rich cordierite-anthophyllite-mica gneisses that contain lenses and thin layers of cordierite-anthophyllite-staurolite rocks. What may well be the same unit crops out on the east side of the type Malene unit on Store Malene and the islands to the south. Similar rocks form

part of a thick unit of Malene paragneiss in central Ameralik (Roberts, 1979).

These gneisses are generally depleted in CaO, Na<sub>2</sub>O, and K<sub>2</sub>O and enriched in MgO and Al<sub>2</sub>O<sub>3</sub> compared with all common sediment types. They have very high contents of incompatible trace elements such as Y, Zr, and Nb reflected in high contents of zircon and niobian rutile (Dymek, 1983). Some combination of processes that reworked altered mafic volcanic rocks may have been involved in their genesis. Beech and Chadwick (1980) discussed the chemistry of these gneisses in considerable detail and concluded that the parent sediments could have been mixtures of quartz and Mg-rich clay minerals. On the basis of zircon morphologies, they suggested a detrital origin for the quartz. Higher iron contents and the presence locally of disseminated magnetite and gedrite-magnetite lenses suggest precipitation of additional iron in the parent sediments of the quartz-garnet-sillimanite association. Friend (1975) discussed the origin of similar rocks in the southern part of the Fiskenæsset region.

(d) *Mica-rich and quartzofeldspathic metasediments* of probably detrital origin form part of several Malene units. Quartz-plagioclase-biotite gneisses with smaller quantities of sillimanite, muscovite, microcline, and garnet that crop out on Rypeø have been described in some detail by Dymek *et al.* (1983). No primary sedimentary structures have been recognized, but the considerable lithological variation and general arkosic composition were considered to indicate heterogeneous sedimentary protoliths, possibly alternations of sandy, silty, and muddy sediments in a near-shore environment.

A lens of graphite-bearing mica schist enclosed in Malene amphibolites on the north side of Kobbefjord has REE and other chemical characteristics that suggest derivation of the parent sediments from basic igneous material like the protoliths of the Malene amphibolites (McLennan *et al.*, 1984). Rusty-weathering garnet-mica-graphite-bearing gneisses on northern Storø in Godthåbsfjord make up one of the largest bodies of Malene paragneisses. Their trace element chemistry suggests a mixed source of mafic volcanics with felsic volcanics and/or tonalitic gneisses (McLennan *et al.*, 1984.).

### 3. Age

A minimum age for the type unit of Malene supracrustals is given by the fact that on southeast Bjørneøen this unit is intruded by tonalitic Nûk gneisses that have yielded zircon ages of 3070 and 3020 Ma (Baadsgaard and McGregor, 1981).

Rb/Sr whole rock dating of Malene supracrustal rocks yielded a scatter between 2500 and 2800 Ma reference isochrons (unpublished Oxford University data). Zircons from Malene metasediments have given a wide range of ages between 2580 and 2960 Ma (Baadsgaard, 1976), which like the Rb/Sr systematics, are considered to be the result of metamorphism.

### 4. Depositional Environment

There is a larger variety of lithologies and more rocks of sedimentary origin in the mid-Archean supracrustal rocks in the Godthåbsfjord region than in most other parts of the West Greenland Archean. Most of the Malene supracrustal rocks, including amphibolites of basic volcanic origin, appear to have been laid down under water. The chemistry of the best preserved Malene basic rocks is similar to that of mid-Archean supracrustal amphibolites in the southern part of the Fiskenæsset region (Friend *et al.*, 1981) where there is no evidence of early Archean rocks. Supracrustal rocks of dominantly basic volcanic origin are the oldest rocks recognized in the Fiskenæsset region and have been interpreted as fragments of Archean oceanic crust (Rivalenti, 1976; Weaver *et al.*, 1982). Friend *et al.* (1981) suggested that the Malene supracrustal rocks in the Godthåbsfjord region may have been primitive oceanic material that overlapped onto the margin of a continent made of Amîtsoq gneisses. Nutman and Bridgwater (1983) suggested that some of the Malene units may have been deposited on a thinned Amîtsoq basement in a zone of ensialic rifting. This is remarked on further in the section below on mid-Archean crustal structure.

### ANORTHOSITIC COMPLEXES

Anorthositic rocks, strongly broken up by later gneisses, occur semicontinuously for more than 150 km from the outer coast at Tre Brødre through Kangerdluarssoruseq (Færingehavn), outer Buksefjorden, Ameralik, Itivdleq, Kapisigdlit kangerdlua, Storø, and Kangiussap nunâ to Ilulialik in inner Godthåbsfjord. Although the anorthositic rocks along much of this tract have been reduced to thin slices and trains of inclusions in the gneisses, it is probable given the large strains suffered subsequently, that they could be all derived from a single layered intrusive sheet. Anorthositic rocks northeast of the head of Ameralik (Nutman, 1982) may also be part of the same sheet.

Where they have not been modified by later intrusions, the contacts of the anorthositic complex are with Malene



supracrustal rocks, or, northeast of the head of Ameralik, with Malene supracrustal rocks and Amîtsoq gneisses (Nutman, 1982). In the Godthåbsfjord region no intrusive contacts have been found. Meta-leucogabbros and meta-anorthosites are the most abundant lithology and are associated with smaller amounts of amphibolites derived from gabbros that contain layers of olivine-hornblende ultramafics. The gabbro-derived amphibolites formed the marginal phases of the complex and occur between the anorthositic-leucogabbroic rocks and the enclosing Malene supracrustal or Amîtsoq gneiss units. In places they have been mistaken for supracrustal amphibolites. Relic cumulate textures are commonly preserved in the less deformed leucogabbros. Only the anorthositic rocks in the Tre Brødre and Færingehavn areas have been studied in any detail (Sharpe, 1975; summarized by Chadwick and Coe, 1983).

Anorthositic rocks in the Fiskenaeset region crop out within an area some 40 km wide and at least 100 km long. They are considered to be parts of a single layered sheet, termed the Fiskenaeset Complex, that was intruded into submarine basic volcanic rocks and subsequently broken up by granitoid sheets, now gneisses, and complexly folded (see Myers, 1981 and 1985a; for recent summaries of the geology and literature). Windley (1970) likened the Fiskenaeset anorthositic rocks to lunar anorthosites and suggested that they might be part of the Earth's primordial crust. Windley and Smith (1976) compared them with early cumulate rocks in calc-alkaline batholiths of Cordilleran type. Neither of these interpretations has been supported by subsequent work. The Fiskenaeset Complex is now considered to be a layered tholeiitic cumulate that is genetically related to the basic volcanic rocks into which it was intruded (Weaver et al., 1981; Myers, 1976, 1985a). The primary magma is deduced to have been a moderately aluminous tholeiitic basalt, which may have been generated by hydrous fusion of previously depleted mantle and which underwent crystal fractionation under low pressure conditions (Weaver et al., 1981).

The southernmost outcrops of the Godthåbsfjord-Buksefjorden anorthositic complex are 55 km from the nearest outcrops of the Fiskenaeset complex. There are many similarities between the two. One notable difference is that chromitites are a characteristic feature of the Fiskenaeset complex throughout most of its extent but have not been observed in the Godthåbsfjord-Buksefjorden anorthositic rocks.

Anorthositic rocks with relic coarse-grained cumulate textures crop out extensively on western Nordlandet. They were intruded into dominantly basic supracrustal rocks and are extensively broken up by later intrusive rocks of dioritic and trondhjemitic compositions. Meta-

leucogabbro rather than meta-anorthosite is the dominant lithology, and there may be a transition in composition between these and the dioritic gneisses that intrude them. Together with their country rocks, the Nordlandet leucogabbros preserve granulite facies mineral assemblages, locally statically retrogressed to amphibolite facies. They may be a different association from the Fiskenaeset and Godthåbsfjord-Buksefjorden complexes.

Lead isotopic data have been reported for anorthosites on Storø and Ivnuagtoq, inner Godthåbsfjord, by Gancarz (1976) and for anorthosites from Buksefjorden, Færingehavn, Ameralik, and western Nordlandet by Taylor et al. (1980). The Pb isotopic characteristics of these anorthosites are similar to those of the gneisses that enclose and intrude them (see under Nûk gneisses).

Although the Godthåbsfjord anorthositic rocks do not preserve as many primary features as those in parts of the Fiskenaeset region, they are the next most extensive, varied, and well preserved rocks of this type in the West Greenland Archean. Potentially the best areas for further study are Storø in Godthåbsfjord and the nunataks Akugdlerssuaq (Nutman, 1982) and Nunatarssuk east of the head of Godthåbsfjord. The west Nordlandet leucogabbro complex has been mapped on a scale of 1:20,000 but has not been studied in any detail.

## NÛK GNEISSES

The term Nûk gneisses is used for all quartzofeldspathic gneisses (deformed granitoid intrusives) in the Godthåbsfjord region that do not contain Ameralik dikes and that intrude and migmatize Amîtsoq gneisses, Malene supracrustal rocks, and the layered anorthositic complexes (McGregor, 1973). It is now apparent that the Nûk gneisses include at least two distinct and probably unrelated generations of rocks.

### 1. Pre-2900 Ma Gneisses

The type Nûk gneisses, those first mapped by McGregor (1973), crop out on the western parts of the peninsulas between Godthåbsfjord and Ameralik and on islands to the SSW. They extend north through the islands of Sadelø and Bjørneøen. The oldest phases are massive, homogeneous, dioritic gneisses that were subsequently intruded by voluminous, polyphase, tonalitic gneisses. The youngest major phases are granodiorites that form thick, homogeneous sheets and the cores of diapiric domal antiforms as well as the matrix of agmatitic units. Smaller bodies of trondhjemitic gneiss cut the other lithologies. Intrusive relations and primary igneous textures are best preserved on eastern Sadelø,

Bjørnefjorden, and northwestern Storø. To the west and south the type Nûk gneisses were affected by intense ductile deformation in a late, NNE-SSW-trending linear belt.

The best isotopic dates obtained on the type Nûk gneisses are U/Pb zircon concordia intersection dates of 3070 and 3020 Ma on early tonalitic phases from southeastern Bjørnefjorden and of 2980 and 2940 Ma on homogeneous, tonalitic gneisses from Nuuk (Godthåb) town (*Baadsgaard and McGregor, 1981*), and a Rb/Sr whole rock isochron age of  $2980 \pm 50$  Ma ( $Sr_i = 0.7022 \pm 0.0003$ ) on a single, thick unit of massive, granodioritic gneiss on the east coast of Bjørnefjorden (*Taylor et al., 1980*). Other specimens from the type Nûk gneisses in Nuuk town give younger and more discordant zircon ages (*Baadsgaard and McGregor, 1981*) and a Rb/Sr whole rock isochron age of  $2770 \pm 170$  Ma (*Moorbath and Pankhurst, 1976*; recalculated by *Taylor et al., 1980*). These younger ages are considered to reflect disturbance of the isotopic systems, associated with subsequent tectonothermal events.

A U/Pb zircon concordia intercept age of  $2982 \pm 7$  Ma (*Garde et al., 1985*) shows that the Taserssuaq tonalite, northwest of the head of Godthåbsfjord, falls within the age range of the type Nûk gneisses. The Taserssuaq tonalite (originally called the Taserssuaq granodiorite) is a rather homogeneous, but multiphase, weakly foliated intrusion that crops out over an area of more than 1500 km<sup>2</sup>.

A reconnaissance study of the chemistry of the type Nûk gneisses was reported by *McGregor (1979)*, who suggested that the more voluminous phases could be the products of partial melting of metabasaltic rocks such as the Malene amphibolites. Further work on their chemistry is in progress at Leicester University.

The quartzofeldspathic gneisses on the Nordlandet peninsula west of Godthåbsfjord (*Macdonald, 1974*; *Reed, 1980*) are not included within the Nûk gneisses because their relations to the type Nûk gneisses across the fjord are uncertain. Except for a few late sheets of diorite, granodiorite, and pegmatite, all of the rocks on Nordlandet have or have had granulite facies mineral assemblages. There has been widespread, patchy, static retrogression to amphibolite facies. Supracrustal rocks are much less abundant on southern Nordlandet than in most other parts of the West Greenland Archean and are highly broken up by the gneisses. They become progressively more common and form more continuous units toward the north. No early Archean rocks have been recognized on Nordlandet. The Pb analyzed from Nordlandet gneisses and leucogabbros is not contaminated by a less radiogenic Amîtsoq-type component as is Pb in Nûk gneisses and anorthositic rocks that are

intercalated with early Archean rocks (*Taylor et al., 1980*). Granulite facies gneisses and leucogabbros from Nordlandet and from Sukkertoppen, 120 km to the north, have yielded a Pb/Pb whole rock isochron age of  $3000 \pm 70$  Ma (*Taylor et al., op. cit.*). This is taken to date the granulite facies metamorphism but shows that the Nordlandet gneisses are probably about the same age as the type Nûk gneisses.

The earlier and most abundant gneiss phases on southern and western Nordlandet are mainly dioritic in composition. They are strongly veined by leucocratic material that appears to be the product of local anatexis of the diorites. Later gneiss phases are coarse-grained, leucocratic trondhjemitic and tonalites and rare granodiorites and granites. They occur as sheets that break up the older rocks into agmatites and as large, massive bodies, in places forming the cores of diapiric domal structures. Their intrusion post-dated deformation of the dioritic gneisses. Minor late plagioclases, composed of 85–90% andesine with hornblende and biotite, are closely associated with basic lithologies, of which they may be anatectic products.

## 2. Post-2800 Ma Gneisses

Dykes of younger trondhjemitic and granitic gneiss within the type Nûk gneisses are termed Qârusuk dikes (*McGregor et al., 1983*). One such dike on southeastern Bjørnefjorden has yielded a U/Pb zircon concordia intercept age of 2660 Ma (*Baadsgaard and McGregor, 1981*). Granodioritic to granitic gneisses of similar age are more extensive in inner Godthåbsfjord (*Coe and Robertson, 1982*; *Robertson, 1983*; *Brewer et al., 1984*). Major, mappable units of late Archean granodioritic gneiss south of Ameralik may also belong to this group. At present the distribution of this group of gneisses is uncertain. The age determinations available are mainly in the range of 2600–2700 Ma.

It is now apparent that earlier collections of rocks that have been used for isotopic studies of Nûk gneisses (*Moorbath and Pankhurst, 1976*; and some of the suites considered by *Taylor et al., 1980, 1984*) are mixed suites that include some post-2800 Ma gneisses. The collections from the Buksefjorden map sheet area comprise older Nûk phases, post-2800 Ma gneisses, and probably also some Amîtsoq gneisses that were affected by late Archean granulite facies metamorphism and subsequent retrogression (see below). Consequently, some of the conclusions reached in these studies can no longer be accepted at face value.

*Taylor et al. (1980)* found that Pb in Nûk gneisses and anorthositic rocks, within the part of the region where early Archean rocks have been recognized, contain

variable proportions of anomalously unradiogenic Pb that they interpreted as derived from early Archean, Amitsoq gneiss-type continental crust. The samples with the highest proportions of Amitsoq-type Pb are probably all from the younger (2700–2600 Ma) gneisses. Sm/Nd analyses reported by *Taylor et al.* (1984) indicate a contribution of Nd from low-Sm/Nd crustal sources for some of the same samples that show contamination with Amitsoq-type Pb. Most of the samples used in this study are from the post-2800 Ma gneisses. The Pb and Nd, together with other chemical characteristics (*McGregor et al.*, 1983) of these rocks indicate an origin by partial melting of sialic crustal rocks that included a substantial early Archean component. High, variable alkali contents and very variable trace element chemistry in the Qârusuk dikes suggest they crystallized in a fluid-rich environment and therefore their chemistry must be regarded as controlled by both igneous and hydrothermal processes.

Many of the Nûk gneisses for which *Compton* (1978) reported REE concentrations belong to the post-2800 Ma group. Older gneisses studied by *Compton* are all from the terrain affected by 2800 Ma granulite facies metamorphism (see below), where Sm/Nd systematics appear to have been upset during the granulite facies metamorphism. *Compton's* data cannot, therefore, be used to discuss the origin of the more voluminous, pre-2900 Ma type Nûk gneisses.

Mid to late Archean gneisses like the Nûk gneisses are by far the most abundant rocks in the West Greenland Archean. They occur mainly as folded sheets that split up sequences of mid-Archean supracrustal and anorthositic rocks and, in the Godthåbsfjord region, also early Archean rocks. The great lateral extent and concordant form of the gneiss sheets is in part the result of extreme attenuation by deformation, but is in part also a primary feature. It appears that the Nûk-type magmas were commonly intruded as sheets along active thrust planes between and within units of older rocks and that differential movement of the walls of the sill as the magmas solidified caused many of them to crystallize with gneissic textures (*McGregor*, 1979; *Myers*, 1978, 1985a,b).

## MID-ARCHEAN CRUSTAL STRUCTURE

The following model is suggested by V.R.M. as a possible explanation of many features of the central part of the West Greenland Archean: Mid-Archean oceanic crust made up of basic volcanics with subordinate anorthositic cumulate complexes and locally derived sediments was carried toward a continental mass of early Archean rocks beneath which it descended in some form

of subduction zone. Detrital sediments derived from the early Archean rocks and from contemporaneous, subduction-related intermediate to acidic volcanics were deposited on the basic volcanics as they approached the continental margin. Slices of the composite supracrustal sequence were intercalated tectonically with the early Archean rocks in the deeper parts of the continent, while mainly basic rocks were flaked off and underplated the continent (*Weaver et al.*, 1982). Dioritic, tonalitic, and granodioritic magmas generated by partial melting associated with subduction and were emplaced along active thrusts mainly in the deeper parts of the pile. There was a tendency for denser, more mafic magmas to accumulate at deeper levels.

According to this model, differences from area to area in the proportions of the early and mid-Archean lithological associations could be explained in terms of different crustal levels:

1. The shallowest level now exposed is in the Isukasia area, which is made up entirely of early Archean rocks. Mid-Archean supracrustal and intrusive rocks are absent.

2. A deeper level is preserved in the tract through Godthåbsfjord where mid-Archean (Malene) supracrustal and anorthositic rocks are intercalated with early Archean rocks. Mid-Archean (type Nûk) intrusives comprise subequal amounts of tonalitic and granodioritic compositions.

3. Much of the Fiskensæset region and northern Nordlandet represent a deeper level still, interpreted in this model as below the base of the early Archean continent. The oldest rocks are mid-Archean basic supracrustal rocks with oceanic affinities and anorthositic cumulates. These are subordinate in volume to mid-Archean intrusives.

4. The deepest level now exposed is on southern Nordlandet. Early Archean rocks are absent and there are only minor amounts of mid-Archean supracrustal rocks derived almost exclusively from basic volcanics. The dominant rocks are mid-Archean leucogabbroic to dioritic intrusives together with trondhjemitic rocks formed by partial melting of the diorites under granulite facies conditions.

The overall structure of the Fiskensæset region may be that of a very large dome centered south of eastern Sermilik (see the 1:500,000 map sheet). The form of the inferred dome has been strongly modified by late Archean folding. In this interpretation, rocks from the deepest exposed crustal level, in which the Ilivertalik granite suite is a major component, crop out in the center of the dome. Early Archean rocks occur only at higher crustal levels on the flanks of the inferred dome to the

north in the Godthåbsfjord-Faeringehavn region and to the south in the Frederikshåb-Ivigut region (*Taylor and Kalsbeek*, this volume).

Nordlandet is interpreted as a tilted block with rocks from progressively deeper crustal levels exposed along a section from north to south.

## LATE ARCHEAN PLUTONIC DEVELOPMENT

Between 3000 and 2500 Ma the region was affected by a complex and as yet rather imperfectly understood sequence of deformation, metamorphism, generation, and intrusion of granitoid magmas and movement of especially minor and trace elements.

### 1. Deformation

The deformational history of much of the region has not been considered in detail. The best studied areas are the Isukasia area (*Nutman and Rosing*, this volume), the Ivisârtoq area (*Hall and Friend*, 1979; *Chadwick*, 1985) and the peninsula and islands southwest of the mouth of Ameralik (*Chadwick and Nutman*, 1979). *Chadwick and Coe* (1983) summarized ideas on the structure within the Buksefjorden 1:100,000 map sheet.

A strong, subhorizontal, planar fabric was probably developed widely in the mid-Archean, associated with thrusting that interleaved early Archean rocks with Malene supracrustal rocks and controlled the intrusion of some Nûk gneiss parents.

In most areas where there are good lithological markers, early recumbent isoclinal folds can be identified and are refolded by one or more generations of upright structures. However, fold phases or sequences of phases with similar styles were not necessarily synchronous from area to area. For example, in the area north of Fiskenaesset large-scale recumbent folds were refolded by two sets of folds with steep axial surfaces at high angles to one another (*Myers*, 1978, 1985b). All three phases *pre-date* granulite facies metamorphism at ca. 2800 Ma (see below). Between Ameralik and the head of Buksefjorden a major recumbent fold, the Inugssugsuaq nappe, that is refolded by large upright folds (*Chadwick et al.*, 1982) is interpreted by us as *post-dating* late Archean granulite facies metamorphism.

Late ductile deformation was concentrated in linear belts, some of which are indicated in Figure 1. One such belt passes through the peninsula on which Nuuk town is situated and separates the granulite facies rocks of Nordlandet from rocks to the east that never reached granulite facies. The rocks in this belt have a strong, subvertical, planar fabric element parallel to the orientation of the belt as a whole and a strong linear

fabric element that plunges in most places at moderate angles to SSW. Toward the south the deformation zone broadens and the planar fabric element becomes less pervasive, although the linear fabric element remains strong. South of the mouth of Ameralik the linear fabric is coaxial with sheath folds that have the form of flattened dunces' caps (*Chadwick and Nutman*, 1979). Structures in the linear belt are consistent with a sinistral strike-slip component of displacement across the belt and a vertical component that brought up the rocks of Nordlandet with respect to those east of the belt.

It is important to realize that most of the rocks in the West Greenland Archean have been affected by one or more episodes of intense ductile deformation that rotated earlier structures into parallelism and streaked out bodies of different lithologies. This produced regularly layered rocks (gneisses, amphibolites, meta-anorthosites, etc.) from parents that may not have been layered at all. *Myers* (1978) has figured particularly clear examples of this process.

### 2. Metamorphism

The belt of rocks that crops out from Faeringehavn through much of Godthåbsfjord to the margin of the Inland Ice in the Isukasia area (Figure 1) and that contains all the rocks that have yielded early Archean isotopic ages differs from the remainder of the northern part of the West Greenland Archean in that it did not reach granulite facies in the late Archean.

Granulite facies metamorphism northwest of this belt appears to have occurred 3000–2950 Ma ago, about the same time as intrusion of the very voluminous Tasersuaq tonalite (see above under Nûk gneisses). Conditions of 800°–850°C and 7–9 kb total pressure have been calculated for granulite facies rocks on southern Nordlandet (*Reed*, 1980) and 825°C and 8.3 kb for rocks a little north of Nordlandet (*Dymek*, 1984).

South and southeast of the Godthåbsfjord region there are areas with granulite facies mineral assemblages separated by areas with amphibolite facies assemblages (see the 1:500,000 geological map and Figure 1). The age of the granulite facies metamorphism around Fiskenaesset is given by: (a) A Pb/Pb whole rock isochron age of  $2810 \pm 70$  Ma for four anorthositic rocks and one gneiss (*Black et al.*, 1973). (b) An essentially concordant age of 2790 Ma for a large euhedral zircon from an ultramafic pod. This zircon is considered to have crystallized during granulite facies metamorphism (*Pidgeon and Kalsbeek*, 1978). (c) A concordia intercept age of  $2795^{+11}_{-7}$  Ma on zircons from the Ilivertalik granite, considered to have been emplaced during granulite facies metamorphism (*Pidgeon et al.*,



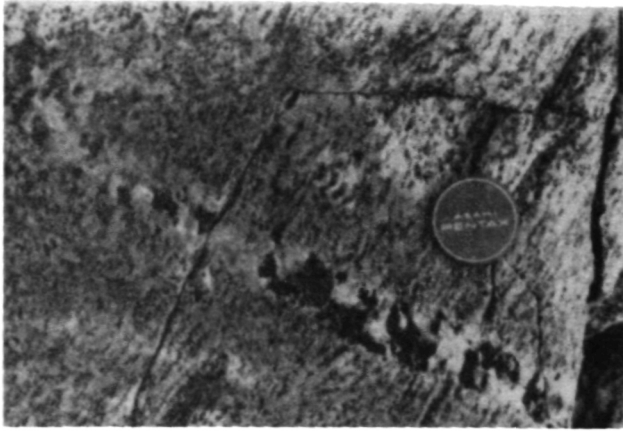


Fig. 2. Big-hornblende pegmatite in retrogressed gneisses with blebby texture, Kangimut sangmissoq, Ameralik.

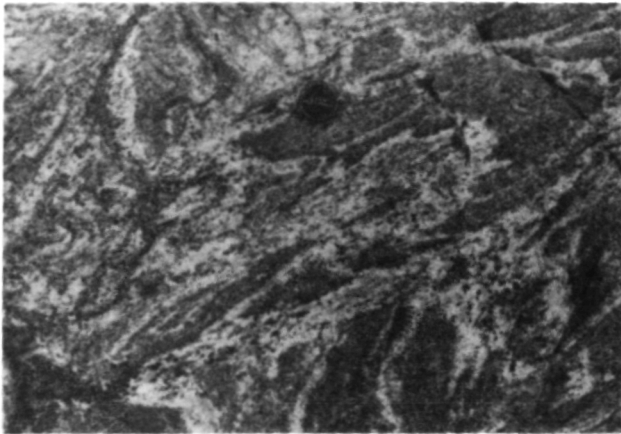


Fig. 3. Pegmatitic patches in mafic gneisses retrogressed from granulite facies, Amitsorssuaq, Buksefjorden.

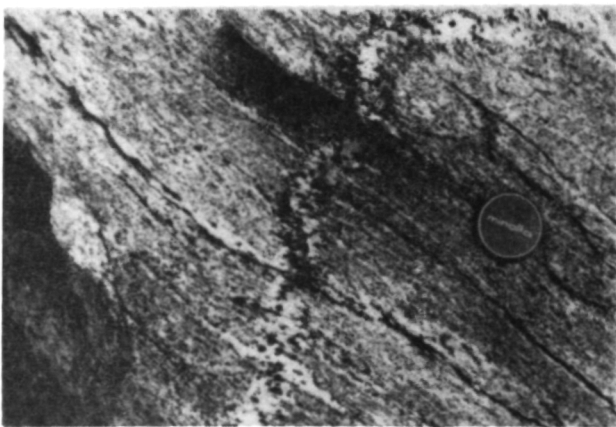


Fig. 4. Slightly deformed big-hornblende pegmatite in gneisses retrogressed from granulite facies, north coast of Buksefjorden.

1976). Granulite facies metamorphism thus appears to be 150–200 Ma later here than northwest of Godthåbsfjord.

Some workers have assumed that the present granulite-amphibolite facies boundaries in the Fiske-næsset and Sermilik-Buksefjorden areas are close to the original prograde boundaries and that granulite facies metamorphism outlasted all major ductile deformation (Wells, 1976, 1979; Myers, 1976, 1978; Chadwick and Coe, 1984). Our own observations indicate that most of the amphibolite facies rocks between Fiskanaæsset and a line that extends NNE through Kangerdluars-soruseq (Færingehavn) and central Ameralik (Figure 1) originally had granulite facies assemblages but have been retrogressed. Retrogression was associated in many places with deformation and, at least in the north, with intrusion of the younger (post-2800 Ma) suite of Nûk gneisses.

Our conclusions are based on recognition of textural features related to crystallization of orthopyroxene that are preserved in relic form in rocks that have been retrogressed to amphibolite facies:

(a) Concentration of mafic minerals in gneisses of intermediate composition into open clusters, giving the rocks a characteristic "blebby" texture (Figure 2). Where retrogression was incomplete, the mafic clusters are seen to be secondary after orthopyroxene or garnet. Diffusely bounded pegmatitic patches were developed that in retrogressed gneisses have prominent, well-separated mafic clots or large hornblende grains (Figure 3).

(b) Blurring of earlier structures in gneisses (for example, original sharp contacts between intrusive phases) produced nebulitic texture. Because of this process of textural homogenization it is not usually possible to separate components of different ages in quartzofeldspathic rocks that have been affected by granulite facies metamorphism.

(c) Occurrence, especially in intermediate gneisses, of discordant pegmatites with prominent large hornblendes (Figures 2 and 4). In places, the hornblendes can be seen to be secondary after orthopyroxene. The thinner big-hornblende pegmatites appear simply to be planar zones in which the gneisses were recrystallized to very large grain sizes.

(d) Abundant mafic-rich pegmatitic patches and veins in basic lithologies (Figures 5, 6). These contrast with the typically very leucocratic pegmatitic segregations formed in basic rocks under high amphibolite facies conditions (Figure 7). In places, however, mafic pegmatitic segregations with clinopyroxene or garnet formed under amphibolite facies conditions.

(e) Small, replacive ultramafic veins and patches made up of orthopyroxene in unretrogressed areas and

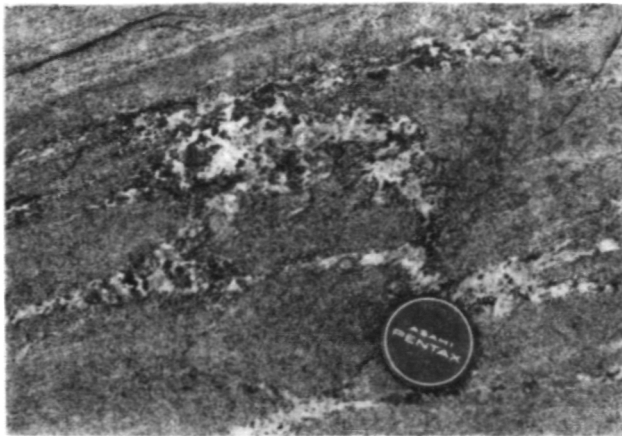


Fig. 5. Mafic segregation pegmatites with orthopyroxene in pyribole (granulite facies mafic rock), Tovqussap nunâ.



Fig. 7. Leucocratic, amphibolite-facies, segregation pegmatite in amphibolite (Ameralik dike), Præstefjord.

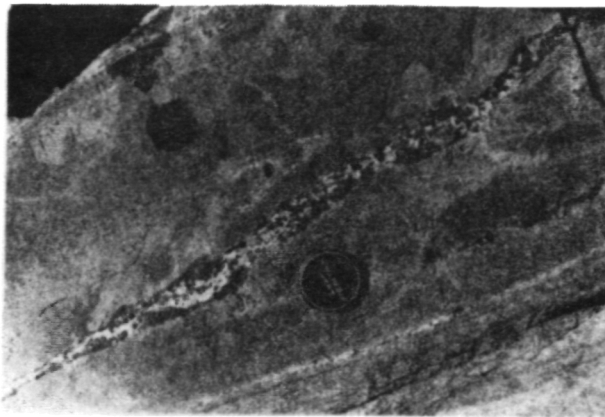


Fig. 6. Mafic pegmatite vein with orthopyroxene in pyribole, Tovqussap nunâ.



Fig. 8. Replacive orthopyroxene patch in pyribole, Tovqussap nunâ.

hornblende in retrogressed areas are common in basic lithologies (Figure 8).

Some or all of these features are found in rocks that were partly or completely retrogressed from granulite facies under static conditions. We have been able to follow these clearly retrogressed rocks into areas where relic granulite facies textural features have been progressively modified and, finally, completely destroyed by deformation with the formation of a new foliation.

The original prograde boundary (Figure 1) between rocks affected by the 2800 Ma granulite facies metamorphism and those to the northwest in the belt through Godthåbsfjord that were not metamorphosed above amphibolite facies in the late Archean has been obscured by retrogression, intrusion of the later suite of Nûk gneisses and the Qôrquut granite complex (see below), major folding, and strong deformation in the late linear belts.

Dymek (1978, 1984) discussed the polyphase metamorphism of the Malene supracrustal rocks. The earliest and highest grade of metamorphism for which petrographic evidence is preserved at any locality ranges from middle amphibolite grade in a zone through western Godthåbsfjord that includes Sadelø and Bjørneøen to hornblende granulite grade on Nordlandet and north of the mouth of Fiskefjord. Metamorphism occurred almost entirely within the sillimanite stability field. However, the highest grade assemblages date from different episodes of metamorphism in different places: early granulite facies metamorphism at 3000–2950 Ma northwest of Godthåbsfjord; amphibolite facies metamorphism at ca. 2800 Ma in parts of the belt through Godthåbsfjord; and metamorphism at 2700–2600 Ma in areas where there was complete recrystallization associated with late deformation, for example, in the linear belt through Nuuk town.

In many places there is petrographic evidence of retrograde metamorphism under conditions where kyanite was stable and that Dymek interpreted as the result of renewed crustal heating and hydration.

Amîtsoq gneisses around and south of the mouth of Ameralik show considerable isotopic evidence of metamorphic crystallization in the period 2700–2500 Ma. This is seen in K/Ar and  $^{40}\text{Ar}/^{39}\text{Ar}$  dates on hornblende (Pankhurst *et al.*, 1973); U/Th/Pb dates on sphene, apatite, and allanite, Rb/Sr relations in hornblende, K-feldspar, apatite, allanite, and sphene (Baadsgaard *et al.*, 1976); and by leachable Pb in feldspars that is considered to come from U-rich inclusions (Gancarz and Wasserburg, 1977). Limited open system behavior is indicated by considerable scatter of points on the Pb/Pb whole rock errorchron (MSWD = 21) and by specimens of mainly basic rocks that scatter about a 2700 Ma Rb/Sr reference isochron (Black *et al.*, 1971). The lower intercept with the concordia of the Akilia zircon chord suggests Pb loss during metamorphism at ca. 2500 Ma (Baadsgaard *et al.*, 1984).

Mineral-chemical studies suggest depths of burial of 15–30 km for rocks now exposed and indicate thick continental crust in the late Archean (Wells, 1979; Dymek, 1984).

### 3. Element Mobility

In common with many other granulite facies terrains, the rocks affected by late Archean granulite facies metamorphism in southern West Greenland are strongly impoverished in U, Th, Rb, and K (Kalsbeek, 1974, 1976). The airborne radiometric survey (Secher, 1976, 1977; Secher and Steensfelt, 1981) shows low levels of radioactivity, reflecting low contents of K, U, and Th, in areas where granulite facies mineral assemblages are still extensively preserved on Nordlandet and in the area north of Fiskenaesset (Figure 9). A belt with very low radioactivity extends NNE from the mouth of Sermilik through Buksefjorden to and beyond the middle of Ameralik. Most of the rocks in this belt now have amphibolite facies mineral assemblages, but there is widespread field evidence that they have been retrogressed from granulite facies. The western margin of the low radioactivity belt corresponds to the position of the prograde granulite-amphibolite facies boundary indicated by field evidence. Areas with higher radioactivity to the southeast correspond at least in part to outcrops of more potassic rocks including the Ilivertalik granite (see below). The airborne radioactivity survey shows a belt with unusually high radioactivity immediately west of the original prograde granulite-

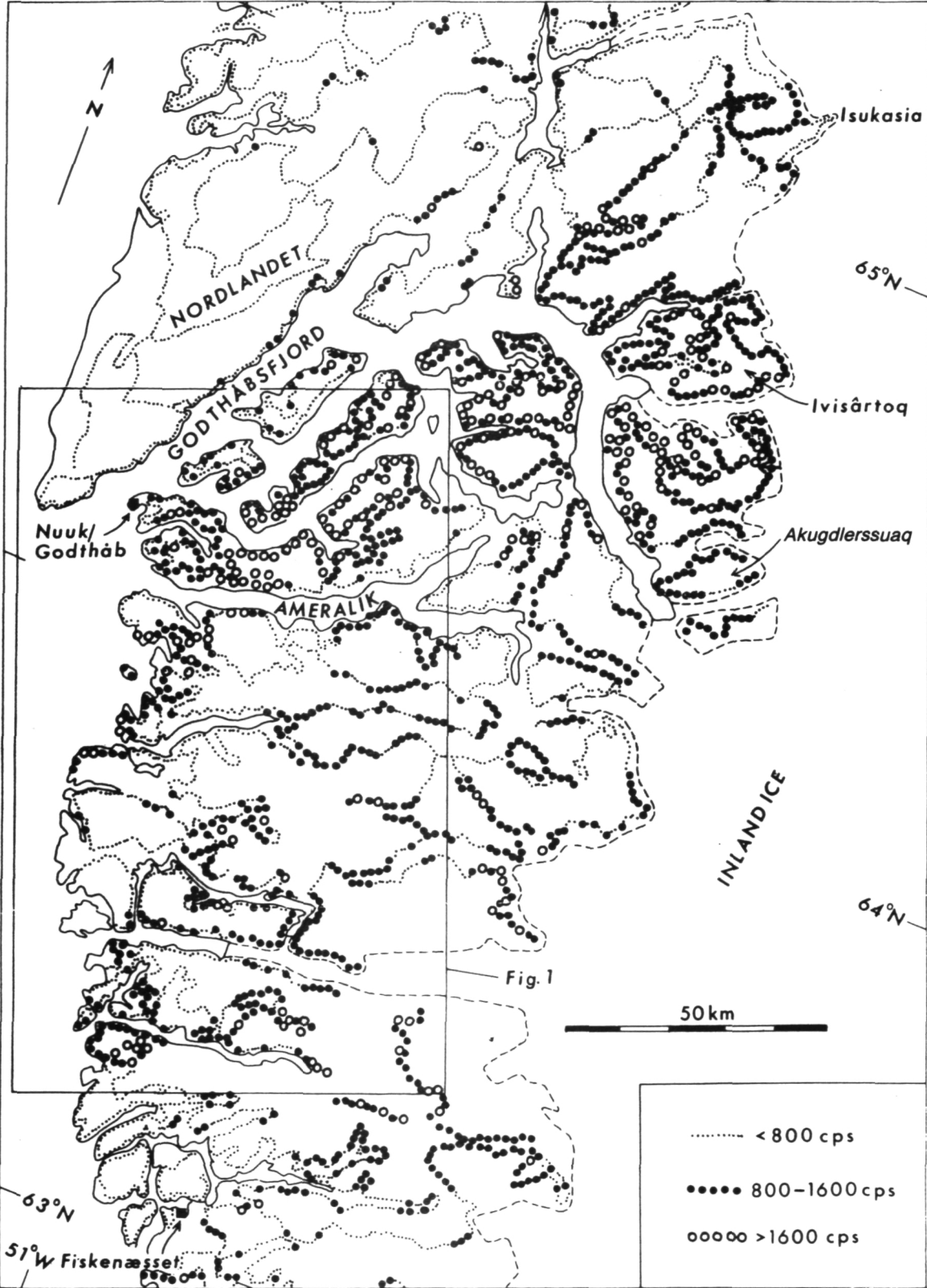
amphibolite facies boundary, i.e., on the amphibolite facies side and presumably structurally just above rocks affected by granulite facies metamorphism. In part, the high radioactivity reflects the outcrop of the Qôrqt granite complex (see below) and other late granitic rocks, but Amîtsoq gneisses within the belt and, in inner Godthåbsfjord, Nûk gneisses also have high levels of radioactivity. The high radioactivity belt is relatively narrow south of Ameralik, but widens to the northeast. This may in part be the result of late deformation, with attenuation of the belt in linear deformation zones to the south and repetition by folding to the northeast.

The high radioactivity belt appears to be a zone of accumulation of elements including K, U, Th, Rb, and Pb that were expelled from deeper rocks affected by 2800 Ma granulite facies metamorphism. Amîtsoq and Nûk gneisses within the belt in inner Godthåbsfjord are enriched in K, Rb, and Pb compared with their equivalents outside the belt, and Sr and Pb isotopes indicate that this enrichment could not have occurred much earlier than 2800 Ma (S. Robertson, personal communication). The enriched zone was probably the source region of granites formed by partial melting (? associated with renewed heating and influx of aqueous fluids) during the period 2700–2500 Ma. The largest volumes of late granites, e.g., the “main body” of the Qôrqt granite complex (see below), may have been generated where the enriched zone had been thickened as a result of folding.

Rb/Sr, Pb/Pb, and systems appear to have been highly disturbed by the 2800 Ma granulite facies metamorphism south of Godthåbsfjord. This is seen most clearly in specimens from a unit of what we confidently interpret as early Archean Amîtsoq gneisses that crops out on the south coast of Ameralik between Kangimut sangmissoq and Qasigiánguit (Figure 1; see locality 3.3. in the Excursion Guide). Specimens from this unit that we consider must include a large proportion of Amîtsoq gneisses yield a Rb/Sr whole rock isochron age of  $2270 \pm 180$  Ma with  $\text{Sr}_i = 0.7019 \pm 0.00005$  and a Sm/Nd model age of ca. 2800 Ma. The pattern of Pb isotopes in the samples is analogous to the pattern in the type Nûk gneisses, with between 1% and 33% of an Amîtsoq-type component in the Pb in 16 samples and about 49% in 2 samples (Jones *et al.*, this volume; Collerson *et al.*, this volume).

The obvious differences between the type Amîtsoq gneisses in outer Ameralik and the gneisses at Kangimut sangmissoq-Qasigiánguit are the following: (a) The latter were recrystallized during the late Archean under granulite facies conditions and subsequently retrogressed to amphibolite facies, while the type Amîtsoq gneisses were not metamorphosed above amphibolite facies in the same period. (b) The Kangimut sangmissoq-





Qasigiánguit unit of Amítoq gneisses is enclosed in and probably to some extent also penetrated by Nûk gneisses. The type Amítoq gneisses in outer Ameralik lie within a 1600 km<sup>2</sup> tract of early Archean rocks interrupted only by thin units of Malene supracrustal rocks. Nûk gneisses penetrate the margin of this tract, but occur only very locally within it.

The type Amítoq gneisses retain early Archean Rb/Sr, Pb/Pb, and Sm/Nd (K. D. Collerson, personal communication) whole rock systematics. We conclude that resetting of these systems in the gneisses at Kangimut sangmissoq-Qasigiánguit is the result of processes associated with granulite facies metamorphism and subsequent retrogression. Proximity of Nûk gneisses may also have been a contributing factor.

*Kalsbeek and Pidgeon* (1980) considered Rb/Sr isotope systematics of gneisses of Nûk type in the Fiskenaesset region for which zircon U/Pb results suggest ages of at least 2900 Ma. They found that the isotopic characters could be explained if the rocks had suffered large-scale Sr isotope homogenization after their emplacement, probably at ca. 2800 Ma, and small-scale isotope homogenization during later metamorphism.

*Grant and Hickman* (1984) pointed out the lack of Sr isotopic evidence for a history prior to 2800 Ma in gneisses from the terrain affected by late Archean granulite facies metamorphism south of Godthåbsfjord and from what we interpret as the enriched zone in inner Godthåbsfjord. They concluded that if the Nûk-type gneisses in this terrain were broadly cogenetic with the type Nûk gneisses that escaped granulite facies metamorphism, then addition of Rb, loss of Sr, and lowering of <sup>87</sup>Sr/<sup>86</sup>Sr ratios through complete isotopic equilibrium with a reservoir containing unradiogenic Sr were all required to account for the isotopic differences.

### CAUSE OF LATE ARCHEAN GRANULITE FACIES METAMORPHISM

*Kalsbeek* (1976) suggested that the depletion in U, Th, and Rb observed in granulite facies rocks in the northern part of the Fiskenaesset region might be the result of partial melting that produced granites such as the Ilivertalik granite complex and left a residue of hypersthene gneisses. The Ilivertalik granite complex crops out very extensively as thick folded sheets of homogeneous augen gneiss in the center of the terrain affected by 2800 Ma granulite facies metamorphism (*Kalsbeek and Myers*, 1973; *Myers*, 1976. See the

1:500,000 geological map sheet). It is interpreted as intruded during granulite facies metamorphism (*Pidgeon et al.*, 1976). The parent lithology was granite with large potash feldspar megacrysts associated with smaller amounts of layered tonalite and diorite. *Wells* (1979) concluded that the chemistry of the granulite facies gneisses north of Sermilik did not support Kalsbeek's hypothesis. Field evidence does not indicate extensive partial melting and segregation of granitic melts at the present level of exposure during granulite facies metamorphism. The disruption of older lithologic units was not associated with granulite facies metamorphism, but with intrusion of the parents of the Nûk gneisses and equivalent rocks.

*Wells* (1979) suggested that granulite facies metamorphism in the Buksefjorden area was the result of heat transferred to the crust by intrusion of the Nûk magmas. This view was based on acceptance at face value of *Moorbath and Pankhurst's* (1976) whole rock isochron ages of between 3000 and 2750 Ma for rocks collected as Nûk gneisses. It is now apparent that these dates reflect metamorphic or metasomatic processes rather than the intrusion of the Nûk parent magmas. Dates from outside the terrain affected by granulite facies metamorphism (the type Nûk gneisses in western Godthåbsfjord and gneisses in the southern part of the Fiskenaesset region; *Pidgeon and Hopgood*, 1975; *Pidgeon and Kalsbeek*, 1978) indicate that the parents of the bulk of the gneisses in this part of the West Greenland Archean were intruded before 2950 Ma. However, isotopic data show that granulite facies metamorphism in the Fiskenaesset region occurred at, or at least continued until ca. 2800 Ma. It is clear from *Well's* (1980) calculations that heat transported to the crust by Nûk-type magmas before 2950 Ma would have been lost by conduction before 2800 Ma.

The mechanism suggested by Wells does not seem appropriate for the granulite facies metamorphism south of Godthåbsfjord, but it may possibly explain the granulite facies metamorphism northwest of Godthåbsfjord, which present data suggest occurred shortly after or at the same time as the intrusion of later phases of the type Nûk gneisses and the Taserssuaq tonalite. Some differences between granulite facies metamorphism on either side of Godthåbsfjord are summarized in Table 1.

A possible model for the 2800 Ma granulite facies metamorphism south of Godthåbsfjord is that it was caused by an influx of heat and fluids from the mantle,

Fig. 9. Radiometric map of the Godthåbsfjord region and the northern part of the Fiskenaesset region, based on air-borne gamma-spectrometric survey from *Secher and Steenfelt* (1981). Values in counts per second.

Table 1. Comparison of late Archean granulite facies metamorphism northwest and south of Godthåbsfjord

NW of Godthåbsfjord (Nordlandet-Qugssuk)	S of Godthåbsfjord (Buksefjorden-Sermilik-Fiskenæsset)
Age: 3000–2950 Ma	Age: ca. 2800 Ma
"Blebbly" gneisses, big-hornblende pegmatites rare or absent	Extensive textural modification produced "blebbly" and nebulitic textures in gneisses and (retrogressed) big-hornblende pegmatites
Extensive partial melting under granulite facies conditions	Limited partial melting under granulite facies conditions
No rapakivi-type granites	Associated with intrusion of rapakivi-type Ilivertalik granite suite
No high radioactivity belt along original prograde boundary to the east in Qugssuk	High radioactivity belt enriched in K, U, Th, Rb, Pb along original prograde boundary to the northwest

possibly through intrusion of basic magma near the base of the crust. The Ilivertalik granite complex could be the product of melting of deep crustal rocks by a mechanism like that proposed for the Amitsoq iron-rich suite (Nutman *et al.*, 1984), with which it has chemical similarities. Fluids migrating upwards through the crust could have caused extensive recrystallization to orthopyroxene-bearing assemblages with the textural features noted above. They could be the agents that moved U, Th, K, Rb, and Pb out of the rocks that developed granulite facies assemblages and into the enriched zone above the prograde granulite-amphibolite facies boundary. They could be the cause of movement of Sr and fractionation of the REE. Rb, Pb, U, and the light REE may have been reintroduced during subsequent retrogression (Bridgwater *et al.*, 1985).

### QÔRQUT GRANITE COMPLEX

Late, essentially post-tectonic granites crop out within a belt that extends from the mouth of Buksefjorden NNE through Qôrqt and Ũmánap suvdlua into inner Godthåbsfjord. These rocks are now termed the Qôrqt granite complex (Brown and Friend, 1980; Brown *et al.*, 1981), having originally been called the Qôrqt granite (McGregor, 1973). The largest area of continuous outcrops of granite (referred to as the "main body" of the complex) lies between Ameralik and Kapisigdlit kangerdlua (Figure 10) and is made up of a very large number of discrete sheets with abundant enclaves and rafts of country rocks (Figure 11).

Samples from the northern part of the "main body" yield a U/Pb zircon concordia intercept age of 2530

± 30 Ma (Baadsgaard, 1976). Moorbath *et al.* (1981) reported Rb/Sr and Pb/Pb isotopic data on a varied suite of Qôrqt granites from localities over a distance of 28 km from Ameralik to Sulugssugutip kangerdlua. Twenty-three whole rock samples yield a Rb/Sr errorchron (MSWD = 3.2) age of 2530 ± 30 Ma, with a high  $Sr_i$  value of 0.7081 ± 0.0008, and a Pb/Pb errorchron (MWSD = 3.2) age of 2580 ± 80 Ma with an apparent  $\mu_1$  value of 6.2. For an assumed mean emplacement age of 2550 Ma, four of the samples yield  $\epsilon_{Nd}$  values in the range of -6.7 to -8.1 with  $T_{CHUR}$  model ages of ca. 3000–3100 Ma (Taylor *et al.*, 1984). The isotopic systematics are consistent with an origin by anatexis of mixed sialic crustal rocks that had generally high Rb/Sr ratios and that included a considerable proportion of U-depleted, early Archean gneisses.

The Qôrqt granite complex between Qôrqt and Sulugssugutip kangerdlua is described by Friend *et al.* (1985). The chemistry and petrogenesis of the granites in this area have been studied by Perkins (1984), whose data and conclusions are reported below. Further work on the overall form and internal structure of the "main body" is in progress at Oxford Polytechnic (Davies, in preparation).

The "main body" of the complex is made up mainly of hypidomorphic granular, nonporphyritic granites with very subordinate granodiorites. The granites have been divided into three groups on the basis of field and petrographic characteristics:

Group 1: leucocratic granites, often containing biotite schlieren and lamellae.

Group 2: grey granites, essentially homogeneous biotite granites.

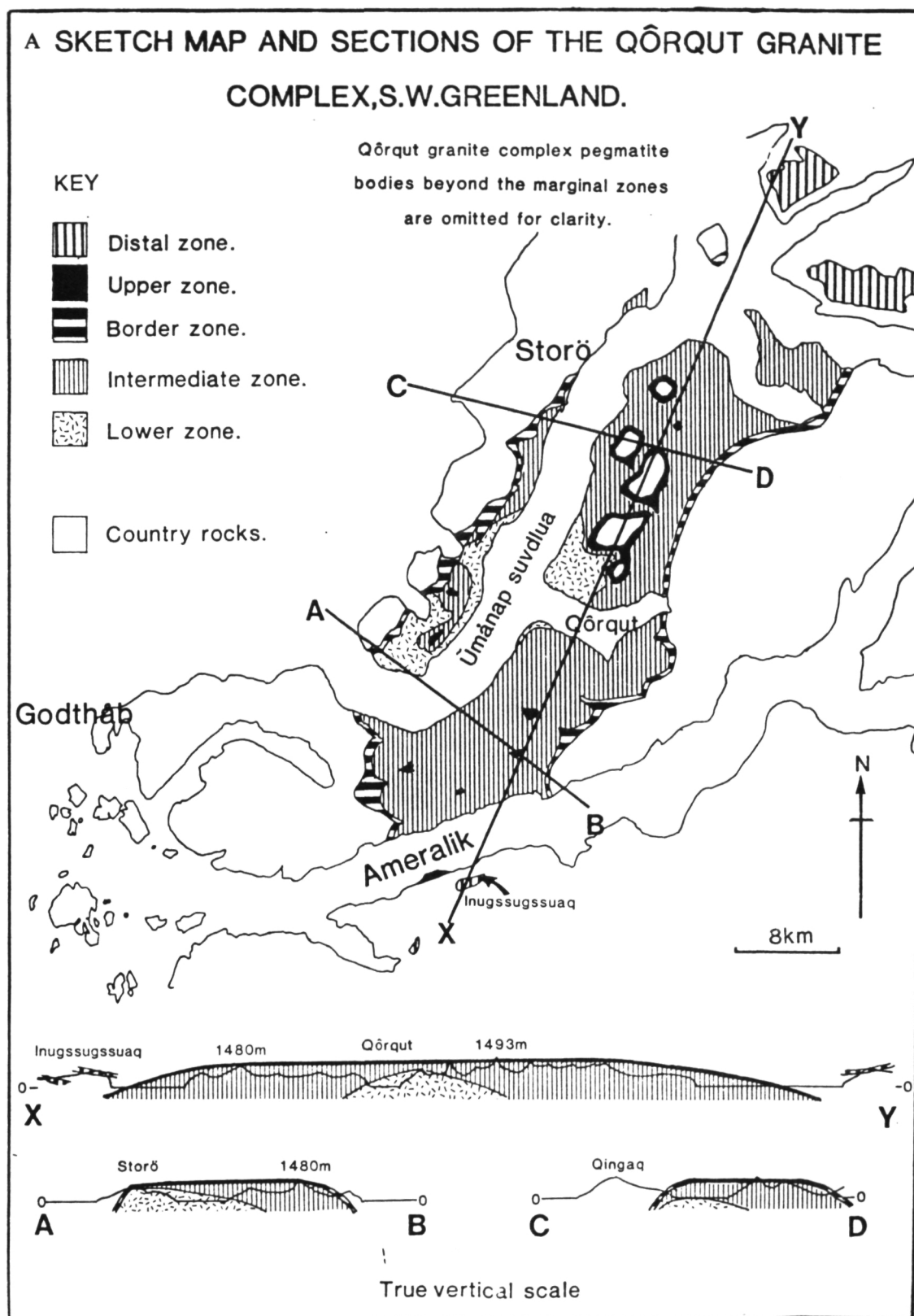


Fig. 10. Sketchmap (a) and sections (b) of the Qôrqut granite complex. (Continued next page.)

**B BLOCK SECTION OF THE QÔRQUT GRANITE COMPLEX  
IN THE AREA BETWEEN QÔRQUT AND AMERALIK**

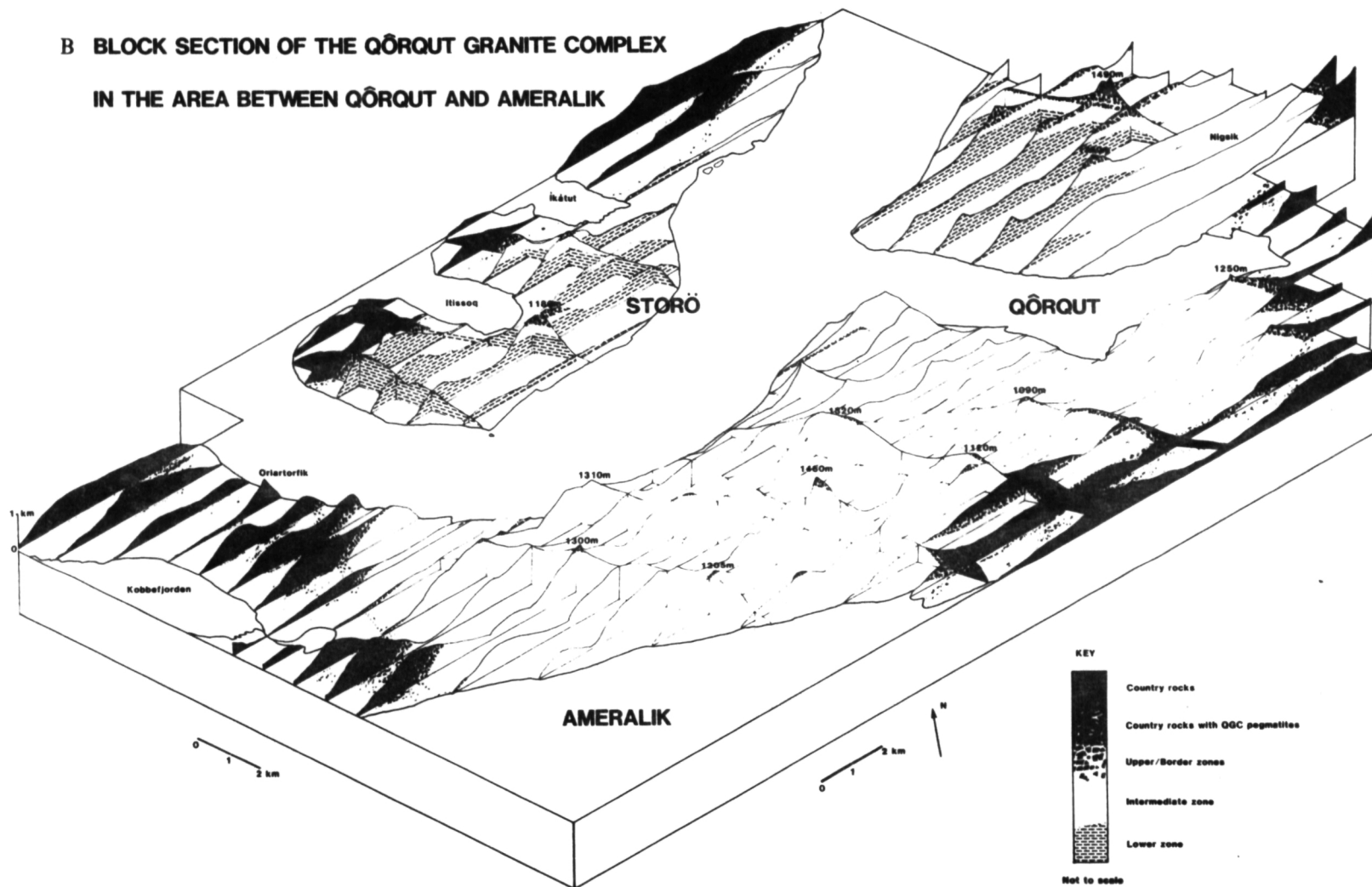


Fig. 10b (continued)

Group 3: composite granites, comprising granite with pegmatite and composite aplogranite-granite pegmatite.

Based on the distribution of these granite types and the included country rock enclaves, the "main body" has been divided into five zones, the characteristics of which are summarized in Table 2 and their distribution shown in Figure 10.

The lower zone is dominated by group 1 inhomogeneous granites which are the earliest phases in the complex. At the western end of Qôrqt the leucocratic granites contain enclaves of Amîsoq and Nûk gneisses that have been modified by anatexis. There is a range of metatexites and diatexites (Figures 12, 13) in these modified enclaves.

Much of the inhomogeneity and schlieric nature of the leucocratic granites is due to the break-up of the metatexites and the formation of inhomogeneous diatexites. Much of the biotite in the granites appears to be derived from biotite ( $\pm$  plagioclase) melanosomes. The chemistry of the granites is consistent with their being mixtures of nonminimum melts and biotite-rich restites. The leucocratic granites have the characteristics of cotectic melts in equilibrium with quartz, plagioclase, and K-feldspar from an environment where  $P_{H_2O}$  approached  $P_{total}$ . Thus the upward movement of these granites was restricted by the negative slope of the granite solidus.

Grey granites predominate in the intermediate zone and the gneiss enclaves they contain have not been modified by anatexis. They are interpreted to have moved some distance above their zone of generation and to have become more homogeneous. Most of the chemical variation, including that of the REE (Figure 14), in the group 1 and 2 granites could have been produced by batch melting of a mixture of crustal gneisses in which biotite was the major ferro-magnesian phase and melted incongruently. Melting models cannot produce the high Rb values unless the source rocks were enriched in Rb. The field, petrographic, and REE evidence suggests crystallization of the group 3 composite granites from  $H_2O$ -rich fluids.

All the granites analyzed plot within the projection of the 685°C isotherm in the granite system at  $P_{H_2O} = P_{total} = 5$  kbar (Figure 15), the lowest pressure for which comprehensive data is available (Winkler, 1979). By lowering  $P_{H_2O}$  to around 3 kbar, complete agreement with the petrographic data could be obtained.

The field, petrographic, chemical, and isotopic evidence thus all support an origin for the granites of the "main body" by partial melting of a mixture of Amîsoq and Nûk gneisses within the enriched zone above the late Archean prograde granulite-amphibolite



Fig. 11. Vertical section through about 2000 m of the Qôrqt granite complex in the vicinity of Sagdlia. The upper zone is drawn from photographs of the 1493 m mountain, the intermediate zone from the mountains north of the Qôrqt hotel and the lower zone from Ujarâ.

boundary. The MSWD of 3.2 for the Rb/Sr errorchron reported by Moorbath *et al.* (1981) indicates a high degree of homogeneity of  $Sr_i$  over a distance of 28 km in the "main body" granites at the time of their emplacement. This is surprising considering that the proportion of Amîsoq to Nûk gneisses in the source region probably varied considerably over the distance



Table 2. Summary of the characteristics of the five zones of the Qôrqut granite complex

Lower zone:	Comprised of dominantly leucocratic granite that contains modified enclaves and some unmodified rafts of country rock all cut by sheets of biotite granite and recut by a few sheets of composite granite.
Intermediate zone:	Comprised of dominantly grey biotite granite of various types that occur as cross-cutting sheets, some of which include subordinate amounts of country rocks and with occasional horizons dominated by country rocks, all of which are cut by composite granites, which are more common than in the lower zone.
Upper zone:	Comprised largely of country rocks as angular rafts enclosed within a network dominantly of sheets of grey biotite granite, the whole forming the host for numerous anastomosing sheets of composite granite that breaks up this host into lozenge-shaped blocks.
Border zone:	Comprised largely of angular blocks of country rocks enclosed within a network of leucocratic granites all of which may be cut by sheets of grey biotite granites.
Distal zone:	Occurring mainly at the NE and SE extremities of the complex and comprising sheets of composite granite and pegmatite cutting country rocks.



Fig. 12. Gneissose melanosome (lower right) giving way to banded metatexite comprising melanosome of biotite-rich layers and leucosome of felsic material.



Fig. 13. Detail of the components of a metatexite showing the hypidiomorphic granular texture of the felsic layers and the biotite-rich melanosome. Note that while there is a prominent banding, the texture is not gneissic.



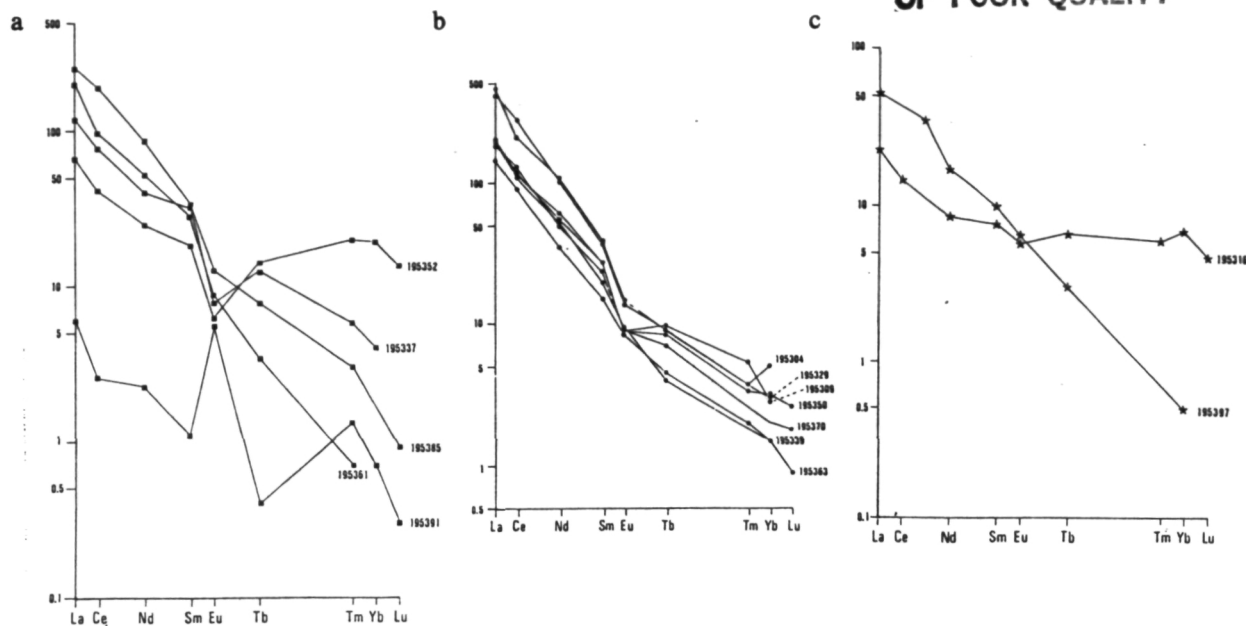


Fig. 14. Chondrite-normalized REE pattern for (a) group 1 granites; (b) group 2 granites; (c) group 3 granites.

sampled. The intrusion of the complex as many small pulses of magma makes the possibility of homogenization of Sr isotopes by convective mixing appear most unlikely.

Undeformed to weakly foliated granites and pegmatite sheets crop out extensively in inner Godthåbsfjord, but are more patchily distributed over a broader area than to the south (*Friend and Hall, 1977; Coe and Robertson, 1982; Brewer et al. 1983, 1984*). The larger outcrops are polyphase, sheeted networks. Rb/Sr and Pb/Pb whole rock ages in the range 2615–2490 Ma confirm that these rocks are similar in age to the “main body” of the Qôrqt granite complex.

Rocks mapped at Qôrqt granite south of the mouth of Buksefjorden (*Sharpe, 1975*) are affected by the deformation in a late, linear belt and are therefore probably older than the Qôrqt granite complex.

### POST-ARCHEAN EVENTS

Proterozoic dolerite dikes are less common in the Godthåbsfjord region than in most other parts of the West Greenland Archean.

The pattern of late faults in the region is interpreted as the result of predominantly simple shear deformation with the greatest principal compressive stress oriented W to NW (*Smith and Dymek, 1983*). The Kobberfjord fault zone through central Godthåbsfjord has a dextral

transcurrent displacement of 5 km and a zone of deformation and strong alteration under greenschist facies conditions about 100 m wide. Quartz-rich mylonites were produced by intense ductile deformation. Proterozoic faulting, alteration, and related phenomena in the Isukasia area are discussed by *Nutman and Rosing* (this volume).

Thermal activity at 1550–1770 Ma is indicated by Rb/Sr dates from micas in Amîtsoq gneisses from south of the mouth of Ameralik and from the Isukasia area (*Pankhurst et al., 1973; Baadsgaard et al., 1976*). A mild thermal event at  $1150 \pm 100$  Ma is indicated by fission track ages from sphene, zircon, and allanite (*Gleadow, 1978*, and personal communication, 1982).

Later intrusions are restricted to a few thin, E-W trending, deuterically altered basic dikes around the mouth of Ameralik, one of which has given a K/Ar age of 57 Ma (*Bridgwater, 1970*), and thin lamprophyres in the Færingehavn-Qilângårssuit area.

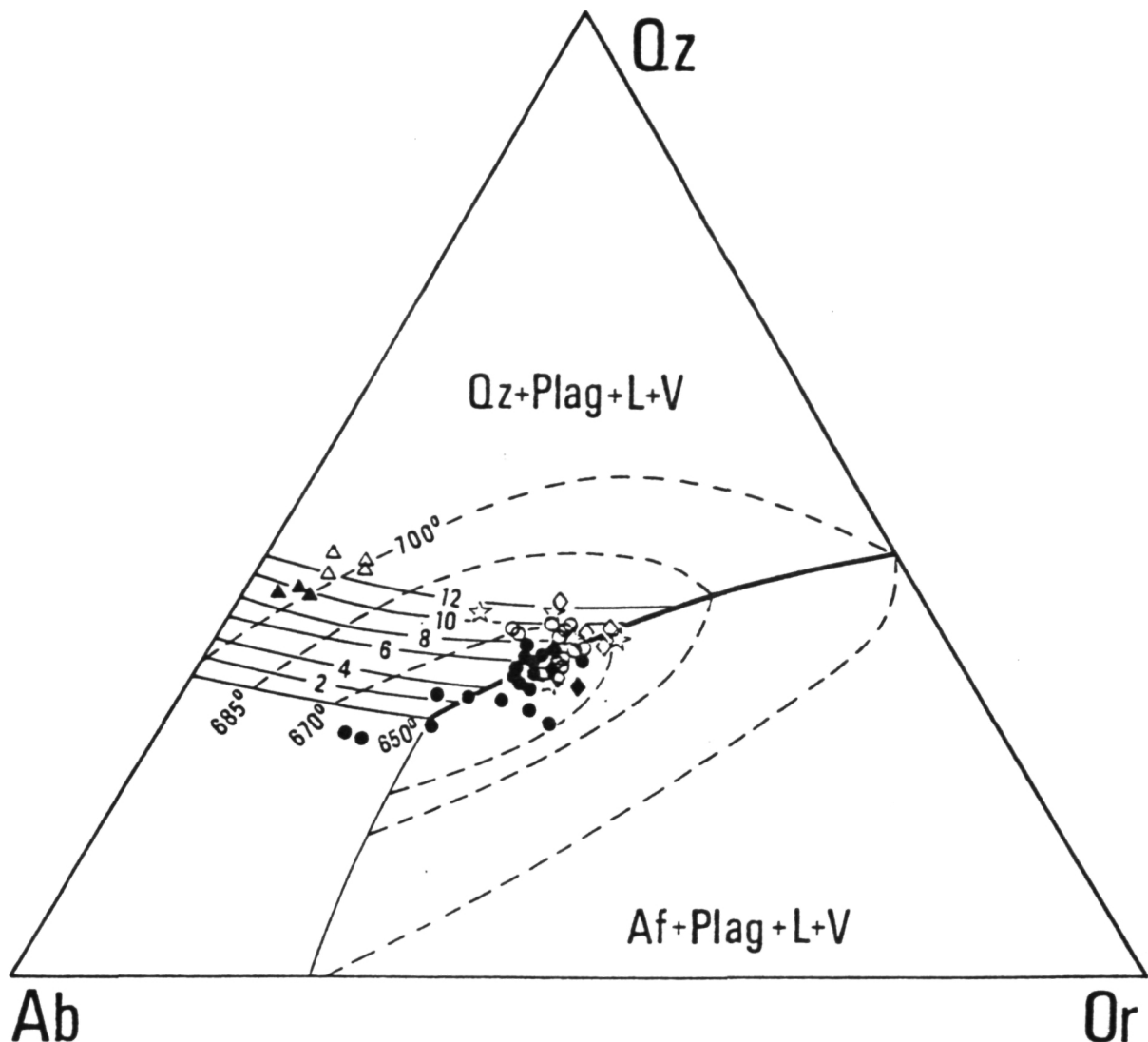


Fig. 15. Analyzed samples from the Qôrqut granite complex plotted with respect to the granite system projected from An onto the base of the tetrahedron. Isotherms on the cotectic surface are projected as dashed lines; also shown are the An contours on the quartz-plagioclase cotectic surface; Symbols: all solid symbols indicate samples that plot above the quartz-plagioclase cotectic surface, open symbols indicate those samples that plot below the surface. Triangles = migmatites; diamonds = group 1 granites; dots = group 2 granites; and stars = group 3 granites.

### Postscript

Some of the hypotheses put forward above must be modified in the light of new discoveries made during our field work in July-August, 1985.

(1) The boundary of the terrain affected by late Archean granulite facies metamorphism in the southern part of the Godthåbsfjord region is sharp and tectonic wherever we observed it from the outer coast south of Færingehavn through Kangerdluarssoruseq, outer Buksefjorden and central Ameralik. It appears to have been a major tectonic

break, probably a thrust. It has been folded and in most places the rocks on either side of it have been strongly affected by post-granulite facies deformation. Between Buksefjorden and Ameralik the tectonic boundary runs close to the eastern of the two anorthositic units that outline the Inugssugssuaq structure, not the western anorthositic unit as indicated in Figure 1. The boundary crosses Ameralik, is folded around the Nipirganeq synform on the north side of Ameralik, and crosses back to the southern side of Ameralik east of Kangimut sangmissoq.

It is now apparent that the zone enriched in K, U, Th, etc. that extends from Færingehavn through Godthåbsfjord and that includes the Qôrquut granite complex does *not* follow a prograde granulite-amphibolite facies boundary at the present level of exposure. It could, however, be related to such a boundary at depth.

The Nûk gneisses with abundant anorthositic enclaves within the Inugssugssuaq structure and at Naujánguit (locality 3.4) are on the northwestern side of the tectonic boundary, within the block that did not reach granulite facies grade in the late Archean. Thus the relationship of these gneisses to the late Archean granulite facies metamorphism cannot be deduced from field relations.

The tectonic boundary runs between the unit of presumed Amîtsoq gneisses at Qasigiánguit-Kangimut sangmissoq and the type Amîtsoq gneisses in outer Ameralik.

(2) A prograde granulite-amphibolite facies transition was observed in one area in inner Bjørnesund, south of Fiskenæsset. Elsewhere in inner Bjørnesund and the next

fjord to the west (Tasiussarssuaq) the prograde boundaries have been obscured by extensive retrogression to amphibolite facies and by some post-granulite facies deformation. The airborne radiometric survey (Secher and Steenfelt, 1981) does not show any very extensive enrichment in K, U and Th in this area.

(3) Several of the textural features described by us as being characteristic of rocks recrystallized during granulite facies metamorphism in the southeastern part of the Godthåbsfjord region were not developed throughout the granulite facies terrain farther south. Spotty pegmatitic patches in the gneisses occur throughout the terrain affected by granulite facies metamorphism. Pervasive blebby texture in gneisses and abundant mafic pegmatites in basic rocks were not observed near the original prograde boundaries, but first appear farther north, around Fiskenæsset. Big-hornblende pegmatites were observed only in the northernmost part of the terrain affected by granulite facies metamorphism.

## EXCURSION GUIDE

## EXCURSION 1

## NUUK TOWN

## Why Nuuk and Nûk?

Over the last 10 years a new orthography for the Greenlandic language has gradually been introduced. Both the new and the old orthography are still used, for example in the newspapers, but the new orthography is now the correct official spelling. The stratigraphic terminology was introduced using the old orthography and this is retained to prevent confusion outside Greenland. Among other things, the new orthography does away with all accents and unsounded consonants. Some examples of spellings in the new and old orthographies are:

Old Orthography	New Orthography
Nûk	Nuuk
Amîtsôq	Amiitsoq
Qârusuk	Qaarusuk
Nagssugtoq (type area for the Nagssugtoqidian fold belt)	Nassuttoq
Itivdleq	Itilleq
Qilângârssuit	Qilangaarsuit
Qôrquut	Qooqqut
Ômánap suvdlua	Uummannap sullua
Kangimut sangmissoq	Kangimut sammisoq

Nuuk (Greenlandic = "the point") is the official name for the administrative capital of Greenland, the Danish name for which is Godthåb. It is the type locality for the mid-Archean Nûk gneisses.

Road cuttings and other blasted sites, the coast south-west of the town, and inland exposures where the lichen has died, all provide excellent exposures of typical polyphase Nûk gneisses with a considerable variety of compositions.

The town area lies within a NNE-SSW-trending belt of late, strong ductile deformation that at a higher level in the crust may have passed into a fault with the western side (Nordlandet) uplifted with respect to the eastern side (the islands and peninsulas in Godthåbsfjord) and with a sinistral (?) strike-slip component of movement. The whole of the peninsula from Nuuk town east past the airport and beyond Store Malene, the high ridge that dominates the view to the east, lies within this deformation belt. To the north, on Bjørneøen, the deformation in the same belt affects late aplitic dikes (Qârusuk dikes, McGregor et al., 1983, see Excursion 4), one of which, outside the deformation belt, has yielded a zircon date of 2660 Ma (Baadsgaard and McGregor, 1981). Movement

in the deformation belt is thought to have overlapped in time with the intrusion of the Qârusuk dikes.

The late deformation has given the rocks in Nuuk town a strong, steeply-dipping planar fabric element that strikes ca. 030°. A regular, linear fabric element that plunges ca. 25° to the SSW is usually conspicuous on foliation surfaces. Both fabric elements are interpreted to be mainly the result of rotation of earlier structures, lithological boundaries, compositional inhomogeneities, etc. into approximate parallelism. Most original discordances between different intrusive Nûk phases have been rotated into concordance. Compare this situation with that seen during excursion 4 in Nûk gneisses on SE Bjørneøen that are part of the same mega-unit, but outside the late deformation belt. There, discordances between intrusive phases are commonly still visible.

The gneisses in Nuuk town enclose and intrude many rafts and enclaves of amphibolite belonging to the Malene supracrustals. These include lithological types with calc-silicate lenses, probably derived from altered pillow lavas, as well as scattered fragments of ultramafic lithologies. Malene amphibolites form extensive rafts cut by sheets of various Nûk gneiss lithologies in the north-west part of the town area and are well exposed on the coast west of the oldest part of the town. Elsewhere in the town area they occur mainly as smaller fragments in the gneisses.

Early, massive dioritic and tonalitic phases make up a belt through the center of the town and contain fewer enclaves of Malene lithologies. The dioritic gneisses form large rafts in the tonalitic gneisses.

A Sm/Nd whole-rock isochron age of ca. 3050 Ma has recently been determined at the University of Alberta on the Nuuk town area samples used for zircon age determinations (H. Baadsgaard, pers. comm.). Rb/Sr and U/Pb systems in most of these gneisses appear to have been affected by later events. An exception is the homogeneous tonalitic gneiss, specimens 152726 and 201415, from Locality 5, Fig. 16, which has yielded a U/Pb zircon concordia intercept date of 2980 Ma with several points on or near the concordia (Baadsgaard and McGregor, 1981). This is the same age as the Taserssuaq tonalite (Garde et al., in press). It suggests the possibility that the belt of more homogeneous tonalitic gneisses that extends through the center of the town area is the extension of the Taserssuaq tonalite, highly attenuated within the late deformation belt.

Eight other specimens from a number of localities within the town area gave considerably more discordant ages in the range 2990-2880 Ma (Baadsgaard and McGregor, 1981). Eleven gneisses that range in composition from dioritic through tonalitic and granodioritic to trondhjemitic, collected from localities across most of the town area, yielded a Rb/Sr whole rock isochron age of 2770

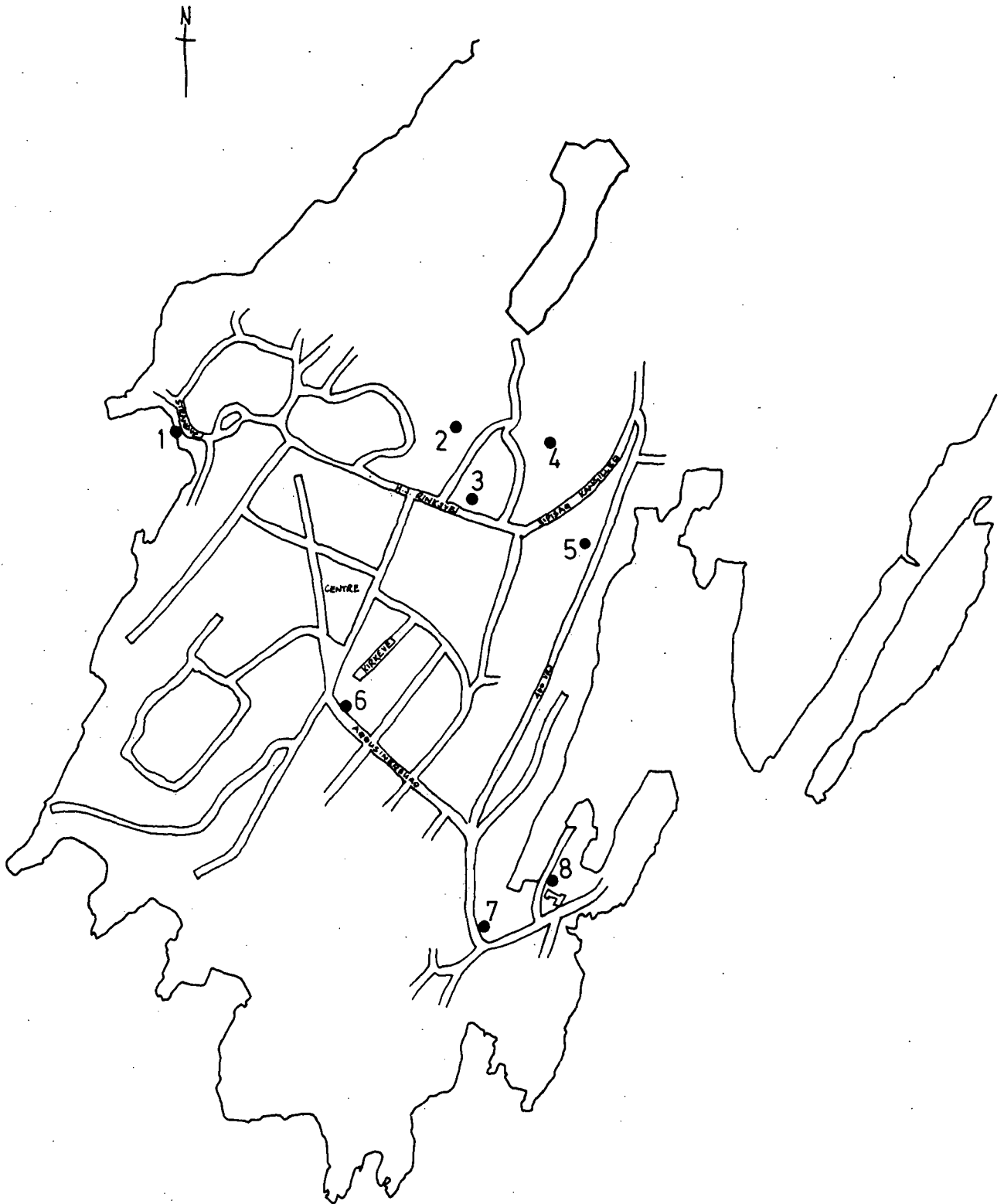


Fig. 16. Localities of some dated and analyzed specimens of Nûk gneisses in Nuuk town.

$\pm 190$  Ma (Taylor et al., 1980). Grant and Hickman (1984) calculated  $T_{UR}^{Sr} = 3388$  Ma for these specimens.

The late deformation belt through Nuuk town separates rocks affected by 3000-2950 Ma granulite facies metamorphism to the west on Nordlandet from rocks that never reached granulite facies to the east. Intense deformation erased almost all evidence of granulite facies metamorphism in rocks in the western margin of the belt where it is exposed on the east coast of Nordlandet. No field evidence has been found to indicate that rocks in Nuuk town were affected by granulite facies metamorphism, but it is a possibility that must be borne in mind. Another possibility is that the isotopic systems were affected by fluids that moved through the deformation belt.

A unit of highly migmatized Amîtsoq gneisses that extends from the islands south of Nuuk to south-west Sadleø (Locality 6.9, Excursion 6) crops out around Nuuk airport. There are few, if any, recognizable Ameralik dikes or early Archean supracrustal rocks in the road cuttings and other blasted sites around the airport. More recognizable Ameralik dikes have been found on the coasts in the western part of the unit.

The following are some of the localities, shown on Fig. 16, where dated and analyzed (Table 3) specimens of Nûk gneisses were collected:

1. Road cutting below and SW of Hans Egede's statue. Sheets of Nûk gneiss separate large rafts of Malene amphibolites. Specimen 131581 is a pegmatite-layered, granodioritic gneiss collected several meters from an amphibolite raft near the western end of the road cutting.

2. Inhomogeneous, "streaky," pale gneisses with migmatized, drawn-out lenses of Malene amphibolites outside the Catholic Church. 131588 is a granodioritic gneiss from the blasted foundation of the chapel.

3. Blasted face behind the Greenland Radio (Kalaallit Nunaata Radioa) building. 131587 is a homogeneous, coarse-textured, granodioritic gneiss. 152725 and 201417 are zircon dated specimens from the same locality.

4. 152724 and 201416 are zircon dated specimens of massive, homogeneous, grey, tonalitic (?) gneiss from a blasted cable line behind the Sports Hall. The zircons are very discordant.

5. Loose blocks of homogeneous tonalitic gneiss left from blasting for the road were collected as specimens 131586 (analysis and Rb/Sr) and 201415 and 152726

(zircon dating). The latter give the most concordant zircon dates in the town area. 152726 was noted to be a little epidotized.

6. Blasted cutting on the north side of road between Magasinet and the bus company's house. There is homogeneous dioritic gneiss (131579) to the west, and homogeneous tonalitic gneiss (131580) which cuts the dioritic gneiss, to the east.

7. Road cutting on the north side of the road just west of the corner. 131582 is homogeneous trondhjemitic gneiss enclosing small, broken-up inclusions of Malene amphibolite.

8. Streaky, granodioritic gneiss (131585) from the road cutting between the Seamen's Home and the marina. Note the strong linear fabric on foliation surfaces.

Table 3. Analyses of Nûk Gneisses From Nuuk Town

	131579	131580	131581	131582	131584	131586	131587	131588
SiO <sub>2</sub>	51.65	65.62	71.76	71.73	67.51	64.48	69.49	70.71
TiO <sub>2</sub>	1.06	0.50	0.20	0.10	0.24	0.56	0.35	0.18
Al <sub>2</sub> O <sub>3</sub>	18.28	16.29	15.11	16.34	17.06	16.40	15.32	15.96
FeO <sup>1</sup>	8.14	3.89	1.06	0.80	1.83	4.17	2.68	1.20
MnO	0.12	0.06	0.01	0.01	0.02	0.05	0.04	0.01
MgO	4.55	1.74	0.46	0.40	1.65	1.85	1.10	0.61
CaO	7.74	3.99	2.10	3.06	2.30	4.47	3.22	2.67
Na <sub>2</sub> O	4.4	4.6	5.3	5.9	5.7	4.6	4.8	5.3
K <sub>2</sub> O	1.59	1.98	2.60	0.99	2.47	1.46	2.18	2.15
P <sub>2</sub> O <sub>5</sub>	0.75	0.26	0.09	0.04	0.05	0.29	0.15	0.08
LOI	0.50	0.58	0.58	0.53	0.49	0.61	0.50	0.48
Total	99.68	99.94	99.39	99.99	99.52	99.41	100.13	99.48
Rb	40	49	47	18	64	46	42	39
Sr	1119	526	735	678	340	690	460	580
Ba	1010	1040	1560	460	520	870	1340	1220
Zn	79	55	21	10	25	53	44	19
Y	19	1	-	-	4	5	5	2
Zr	113	149	138	71	158	150	108	128
Pb	11	14	24	12	22	12	17	15
Nb	6	5	2	3	2	4	2	-
Cr	90	44	22	23	24	50	30	25
Co	28	15	9	12	12	18	11	12
Ni	54	17	-	-	3	21	7	-
U	0.31	0.337	0.51	0.52	0.303	0.37	0.288	0.133

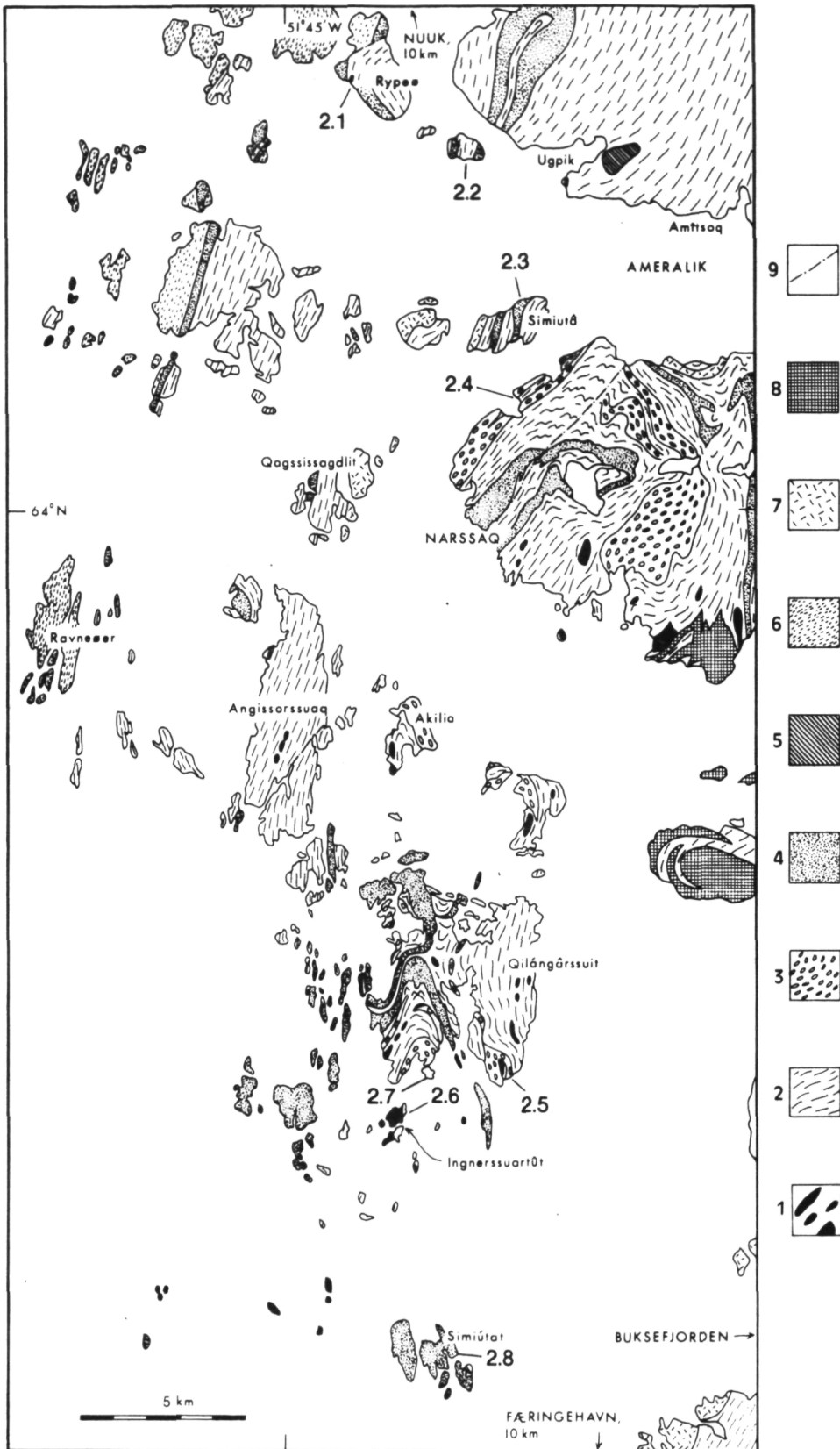
Leeds University XRF analyses, except U, by delayed neutron activation, Risø, Denmark. Major elements in weight percent, minor elements in ppm. Total Fe is reported as FeO<sup>1</sup>. LOI = loss on ignition.

## EXCURSION 2

### NUUK — NORDAFAR — NUUK

Localities for excursion 2 are shown in Fig. 17.

Fig. 17. Geological sketchmap of the outer Ameralik, northwestern Buksefjorden area showing localities for excursion 2. (1) Akilia association; (2) Amîtsoq banded grey gneisses; (3) Amîtsoq iron-rich suite, mostly granodiorite; (4) Malene supracrustal rocks; (5) Ugpik metadolerite; (6) Nûk gneiss; (7) late Archean deformed granitoids; (8) late Archean undeformed granitoids, probably correlating with the ca. 2550 m.y. Qôrqut granite complex; and (9) Proterozoic fault.





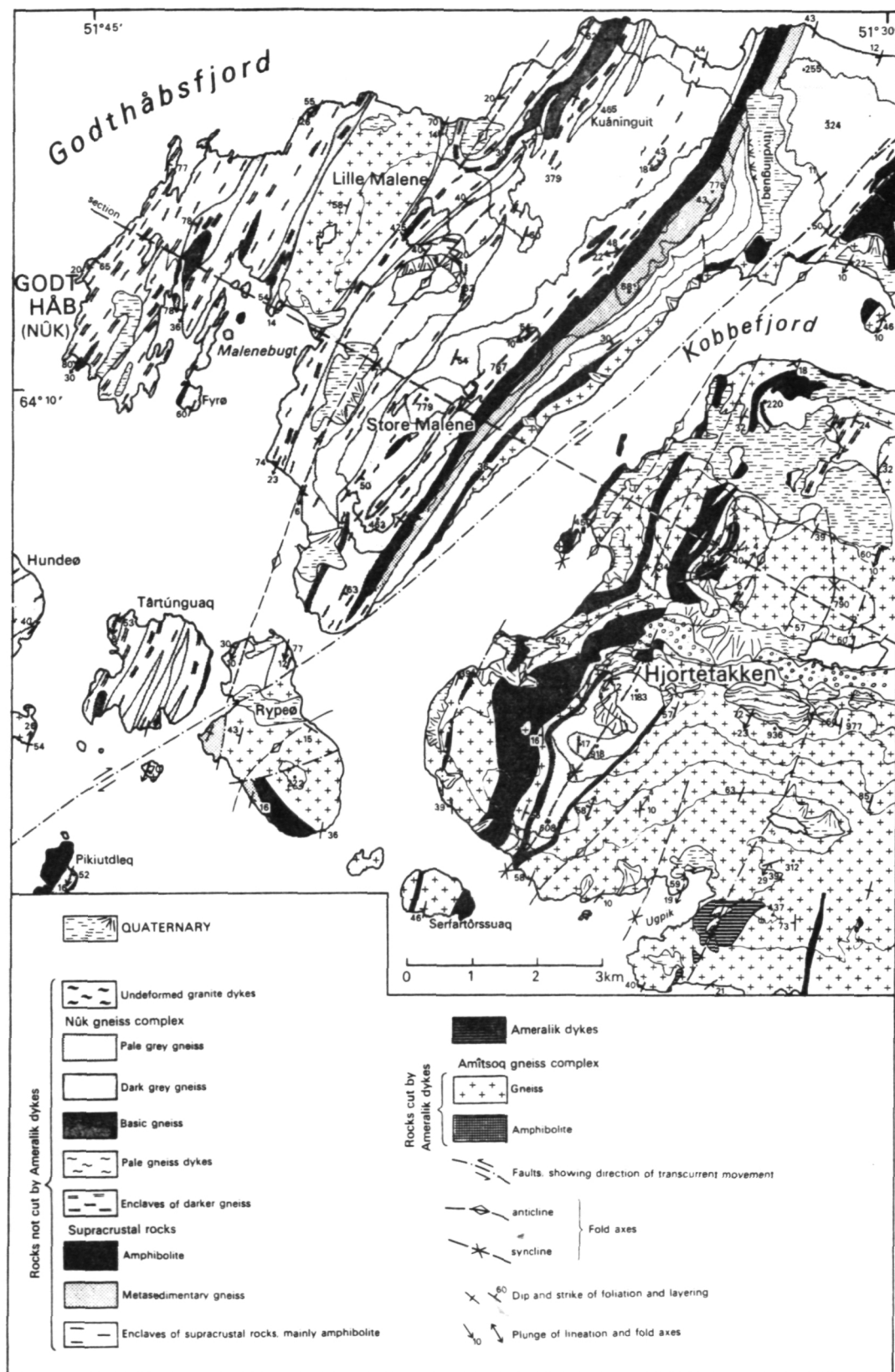


Fig. 18. Detailed map of the area around Godthåb, after McGregor (1973).

As we cross the first stretch of water, between Nuuk and Rypeø, the antiform on Lille Malene can be seen to the north (Figs. 18 and 19). This is one of a row of diapiric domal antiforms that have cores of very homogeneous Nûk granodioritic gneiss. Another of these antiforms will be seen during excursion 4 on southern Bjørneøen (Locality 4.2). Compared with the antiforms to the north, the Lille Malene antiform has been strongly drawn out along a NNE-SSW axis within the late deformation belt.

### Locality 2.1: West Coast of Rypeø

Malene metasedimentary gneisses crop out in two areas, separated by Amîtsoq gneisses, but are probably the same unit. In the southern area they are overlain structurally by Malene amphibolites, which in turn are overlain by Amîtsoq gneisses. Large pods of ultramafic rocks occur along the amphibolite-Amîtsoq gneiss contact. The locality has been described in some detail by Dymek et al. (1983) and copies of their figures are included (Fig. 20).

The Malene metasedimentary gneisses are quartz-rich with abundant plagioclase and biotite and smaller amounts of sillimanite (prominent on foliation surfaces), muscovite, microcline and garnet. Similar lithologies occur only as very thin units elsewhere in the Godthåbsfjord region. REE analyses have been reported by Dymek et al. (1983) and McLennan et al. (1984), and indicate a source for the sediments with REE abundances similar to those in Amîtsoq and Nûk tonalitic gneisses. Sm/Nd characteristics of two samples reported by Hamilton et al. (1983) do not indicate early Archean contributions to the parent sediments.

Only the northern contact between the Amîtsoq gneisses and the Malene metasediments is exposed. We interpret this contact as tectonic and the rocks immediately to the west as including recrystallized cataclasites and intrusive granitoids, the latter now concordant layers of quartzofeldspathic gneiss, as well as gneisses of metasedimentary

origin. Dymek et al. (1983) described a "pod-rock" in the metasedimentary unit near the contact and considered that it could be derived from an intraformational conglomerate or from interlayered sandy to silty sediments. We consider that it may be derived from mica-rich metasediments cut by thin granitoid veins and then highly deformed. Very similar structures occur on SE Bjørneøen where rafts of chlorite-biotite-rich ultramafic rocks were cut by thin Nûk veins and then intensely deformed. Deformation was concentrated in the chlorite-mica-rich lithology and the mica-poor Nûk veins were intensely folded and in extreme cases broken up into pods like those in the "pod-rock" on Rypeø. The Malene units on Rypeø contain other pale grey- to brown-weathering (and in some cases sillimanite-bearing) layers of quartzofeldspathic gneisses of intrusive origin that can easily be taken to be part of the supracrustal sequence. Elsewhere in the region amphibolite units contain sheets of intrusive granitoids, rotated into concordance by strong deformation, that have been described and collected as metasediments.

The Amîtsoq gneiss unit contains a number of thick, tabular bodies of amphibolite interpreted as derived from Ameralik basic dikes. They contain leucocratic symplectic ovoids that are secondary after garnet. The gneisses also contain rafts of other lithologies (Akilia association) that include mafic and ultramafic rocks and a thin layer of quartz-magnetite-actinolite-diopside ironstone.

The Amîtsoq gneiss unit is cut by a dolerite dike that is presumed to be Proterozoic and, near the contact with the southern area of metasediments, by a thin, vesicular, red-weathering dike that is typical of a suite of E-W dikes that occurs around the mouth of Ameralik. A dike belonging to this suite on the north coast of Ameralik between Ugpiq and Amîtsoq has yielded a K/Ar date of  $75.2 \pm 1.1$  Ma (Bridgwater, 1970).

Looking up Kobbefjord, between localities 2.1 and 2.2, one can see abundant large pegmatites in the Malene supracrustal unit on Store Malene. They are presumed

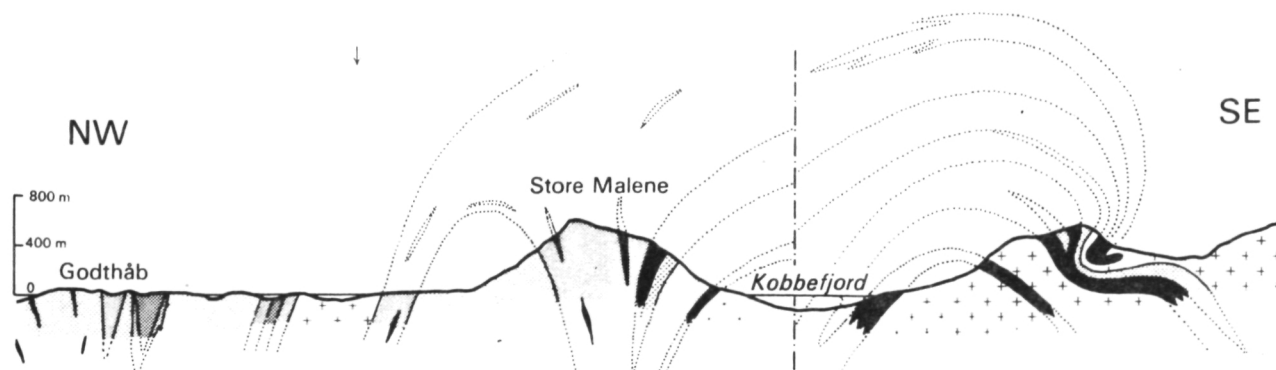


Fig. 19. Geologic section corresponding to dashed line in Fig. 18, after McGregor (1973).

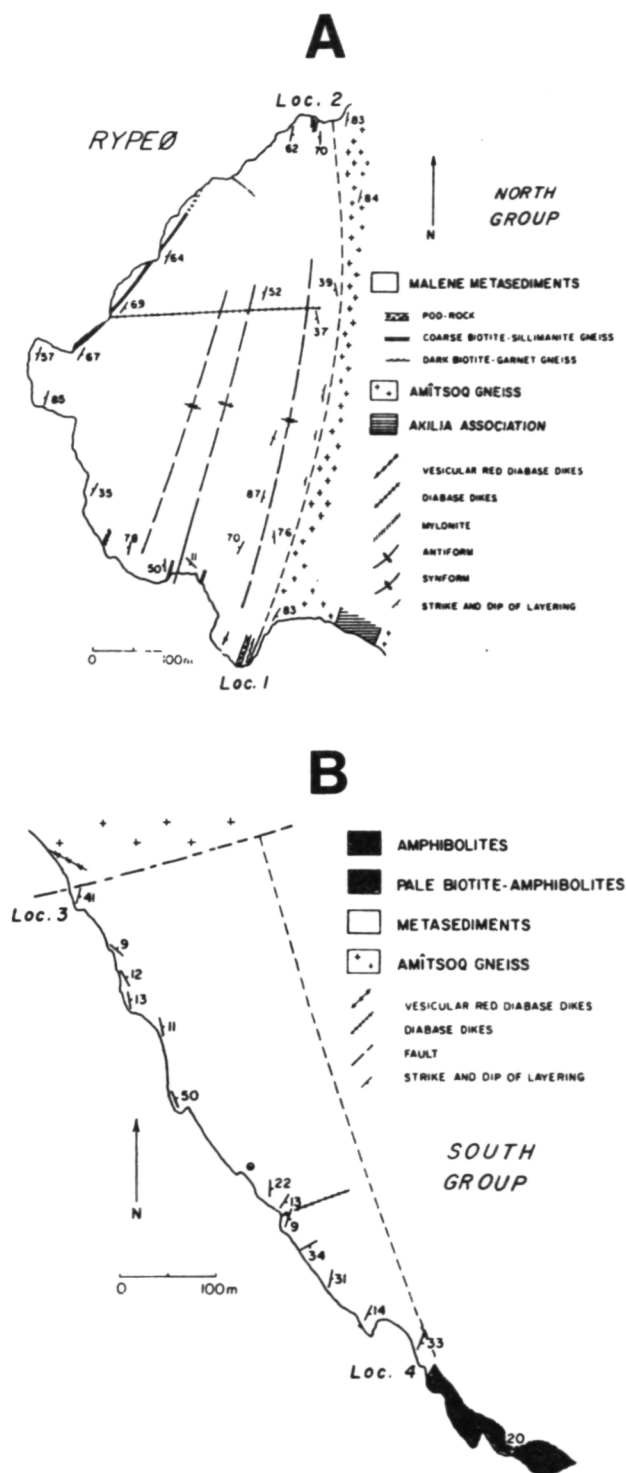


Fig. 20. A: Geology of the northern group of Malene metasedimentary rocks on Rypeø. Akilia association refers to supracrustal (?) enclaves in Amitsoq gneiss as defined in McGregor and Mason (1973). B: Southern group of Malene supracrustal rocks on Rypeø. Both A and B from Dymek et al. (1983).

to be the same generation as little- or undeformed pegmatites in the same Malene unit on Sadleø to the north (see the Qôrqu 1:100,000 map sheet), which have the form of giant tension gashes. The pegmatites on Store Malene, within the late deformation belt, are folded. The original orientation of the pegmatites, as seen on Sadleø, and the folds on Store Malene are taken to indicate the sense of movement in the deformation belt (Fig. 21).

#### Locality 2.2: Serfartôrssuaq

Intercalation of Amitsoq gneisses, Malene supracrustal amphibolites and Nûk gneisses can be seen on the mountain face to the north-east (Figs. 19 and 20). Two different units of Malene supracrustal rocks are visible; a thicker unit to the west (unit C) that is the core of a re-folded, isoclinal, recumbent fold, shown in Fig. 19, and a thinner unit (unit D) that outlines a synform with a core of massive, pale Nûk gneiss. Unit C contains much folded pale pegmatite and gneiss. The two Malene units are separated by a thin unit of well-layered Amitsoq gneisses and by more massive Nûk gneisses intruded along the eastern contact of unit C.

Part of unit C and the thick Amitsoq gneiss unit to the west are well exposed on the south coast of Serfartôrssuaq. The Amitsoq gneisses are well-layered, variable, mainly pale gneisses. They enclose thin, continuous, concordant Ameralik dike amphibolites. One of these that is poorly exposed, but that occurs as detached blocks on the coast, contains the characteristic calcic plagioclase clots. The Akilia association is represented by a few thin layers of laminated amphibolite and a broken-up layer of striped, green-and-black clinopyroxene-hornblende rock. There are many concordant, deformed pegmatites, probably several generations.

The contact between the Amitsoq gneisses and the Malene supracrustal unit is concordant. The western part of the Malene unit is made up of finely laminated ("striped") black and dark green-brown amphibolites that are most likely derived from very highly deformed, altered pillow lavas. To the east, in the core of the isoclinal fold, amphibolites are interlayered with garnet-, anthophyllite-, cordierite-, and staurolite-bearing lithologies. The supracrustal unit contains sheets of strongly deformed pegmatite and grey gneiss Nûk type.

#### Locality 2.3: Simiutâ

On Simiutâ, Malene supracrustal units dominated by amphibolite are separated by gneisses with concordant tabular amphibolites. The gneisses are probably dominantly early Archean, but there are also late Archean granite and pegmatite sheets. The supracrustal rocks may all be the same unit repeated by folding. Symmetrical arrangement of lithologies suggests that the eastern

supracrustal unit is the core of an isoclinal fold. Thin sequences of quartzose rocks, interpreted as metasediments, occur along both contacts between the amphibolites and the enclosing gneisses.

On the north coast, the most complete section is: Amîtsoq-type gneisses with concordant Ameralik dike-type amphibolites; layered quartzite; massive quartzite

(metachert?) with mica schist; layered amphibolite with ultramafic pods. Thicknesses of the Malene lithologies vary considerably along strike, probably because of heterogeneous strain, and tectonic slides have been identified locally. The layered quartzites (243057c, Table 4) are aluminous and contain zircons. Layering is continuous laterally with respect to its thickness. The

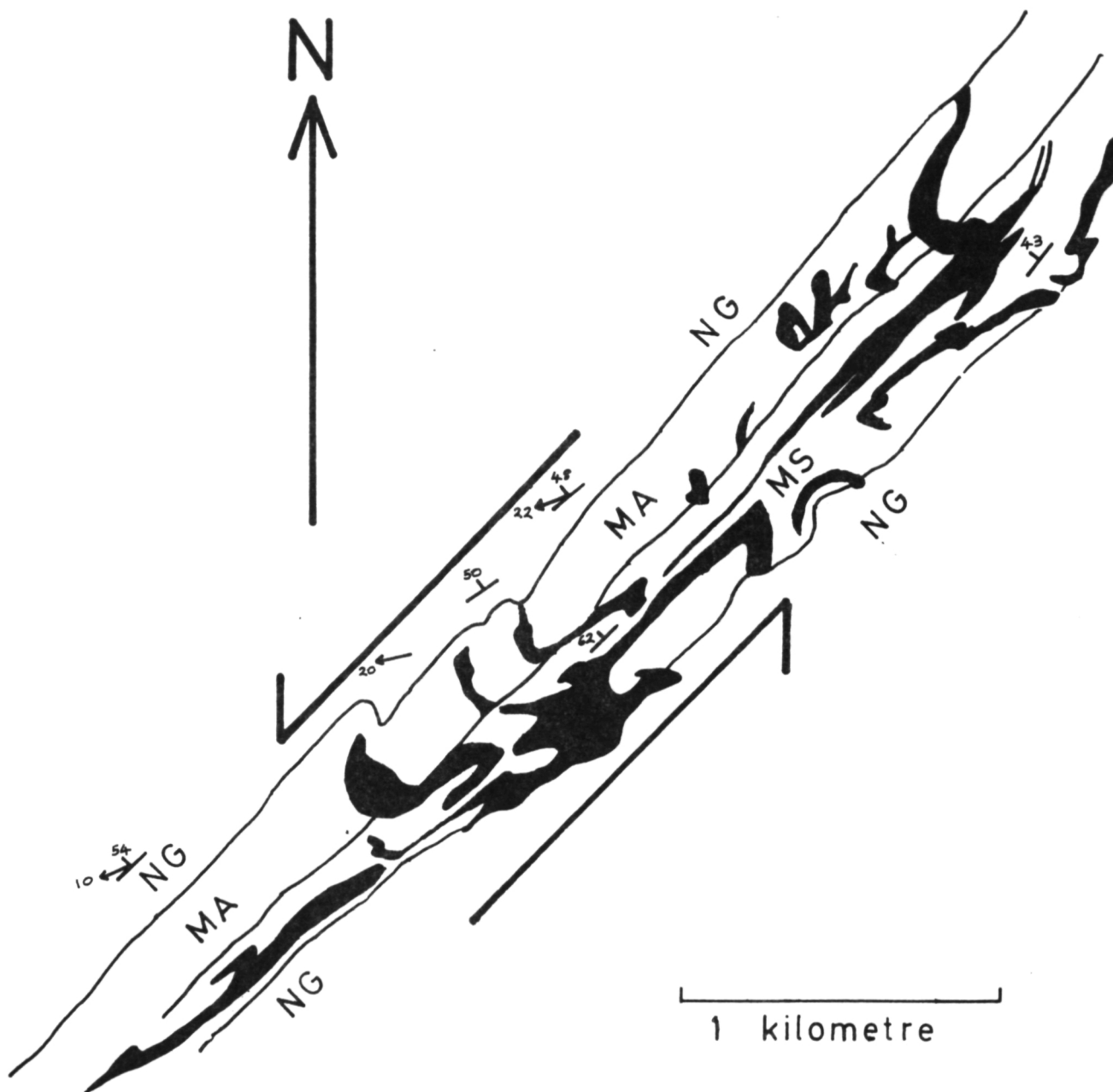


Fig. 21. Deformed (?) Qârusuk pegmatites in the Malene supracrustal unit on Store Malene. The pegmatites are assumed to have been formed as giant tension gashes with NW-SE orientation like those on Sadleø. This orientation has been retained in the more competent Malene amphibolites (MA), while they have been rotated into concordance with the layering of the Malene metasediments (MS). The pattern suggests simple shear deformation with a large vertical component in addition.

massive quartzites are coarse-grained and have a vague layering defined by flecks of amphibole. The associated mica schists are weakly layered and consist mostly of biotite and chlorite with some quartz and feldspar. Locally they have knots of greenish-weathering (Cr-bearing?) white mica. They are rich in Fe, Mg, Ni and Cr and may be sediments derived by weathering of penecontemporaneous basic volcanics. The amphibolites include variable banded types, some with pods of calc-silicate minerals, as well as sheets of very homogeneous amphibolite. The unit contains large pods of peridotite and hydrated equivalents, which may be olivine-pyroxene cumulate facies of layered basic flows or sills.

Nutman and Bridgwater (1983) have interpreted the contact between the quartzites and the Amîtsoq gneisses as a deformed unconformity and the quartzites themselves as fairly mature sediments deposited on an Amîtsoq basement. V.R.M. considers it possible that the contact is tectonic and has been "healed" by intense deformation and metamorphic recrystallization. Quartzites are rare in the Malene supracrustal rocks, but are known to occur locally within amphibolite units, and therefore not only along Malene-Amîtsoq contacts.

#### Locality 2.4: Kanajorssuit

Augen gneiss (deformed big-feldspar granodiorite, analysis 162475, Table 4) of the Amîtsoq iron-rich suite is unusually well preserved here in a small area of low deformation. The effects of progressively stronger deformation on the gneiss and on Ameralik dikes that cut it can be observed along the coastal outcrops to the south.

Where least deformed, the augen gneiss has more or less randomly oriented microcline micropertthite megacrysts in a matrix of quartz, plagioclase, microcline and mafic minerals. The microcline augen comprise relic, single-grain cores surrounded by recrystallized, polygranular aggregates. In rocks where the augen have deformation ratios of more than about 10:1 they are completely recrystallized to granular aggregates. Gancarz and Wasserburg (1977) reported Pb isotopic abundances and other data from feldspar megacrysts from this locality.

Biotite and hornblende are commonly concentrated in clots that also contain apatite, zircon, sphene and magnetite-ilmenite. Where least deformed the augen gneisses range from completely isotropic through rocks with faint igneous (?) layering defined by slight concentrations of mafic minerals to very heterogeneous rocks containing irregular concentrations of mafic minerals. They contain quartzofeldspathic and amphibolitic inclusions, several of which are mantled by concentrations of the mafic clot material. Microcline

megacrysts have grown within and across the contacts of some inclusions.

Along the coast to the south the augen gneiss and Ameralik dikes are progressively more deformed. A marked foliation is developed in the gneiss and the microcline augen become smeared out. Ameralik dikes are folded and progressively broken up. To the south, strongly deformed augen gneiss is in contact with Amîtsoq layered grey gneisses that contain trains of highly broken-up Ameralik dike amphibolites. The fabrics in the gneisses on either side of the contact are parallel. This locality illustrates clearly how difficult it can be to recognize and distinguish different lithologies in the gneiss complexes where, as is normally the case, they are strongly deformed.

#### Locality 2.5: South-East Corner of Qilángárssuit

Augen and ferrodioritic gneisses of the Amîtsoq iron-rich suite are separated by Amîtsoq layered grey gneisses. Augen gneisses were first described here in the early 1800s by Giesecke, the first geologist to work in West Greenland! Berthelsen (1955) described in considerable detail the ferrodiorite and the Ameralik dike that cuts it (Fig. 22).

The ferrodiorite (analysis 155734, Table 4) occurs as a folded sheet ca. 50 m. thick and is rather homogeneous. An area of brown-weathering rock several meters in diameter near the center of the body preserves the assemblage  $\text{opx-cpx-gnt-plag} (\text{An}_{28})\text{-hbd-qtz}$ , which is interpreted to be a relic from the early Archean granulite facies metamorphism. The ferrodiorite is cut by big-hornblende pegmatites like those found in dioritic and tonalitic lithologies affected by late Archean granulite facies metamorphism in the south-east part of the Godthåbsfjord region. Layered Amîtsoq grey gneisses to the west have strongly deformed blebby texture, suggesting that they too are retrogressed from granulite facies, but there is no evidence of previous granulite facies metamorphism in Ameralik dikes in this area, with the possible exception of the dike that cuts the eastern part of the ferrodiorite. Towards its margin, the ferrodiorite has moderately strong foliation and has been retrogressed to amphibolite facies. Contacts with the enclosing layered grey gneisses are sharp and conformable, the result of deformation.

The metamorphosed basic dike that cuts the eastern part of the ferrodiorite is clearly discordant to the folded foliation of the diorite. It contains relic megacrysts of plagioclase that have sericitized cores surrounded by recrystallized aggregates of clear plagioclase (ca.  $\text{An}_{70}$ ). The dike contains hornblende-bearing segregation pegmatites that have some similarity to the mafic pegmatites found in basic rocks retrogressed from granulite facies (Figs. 5 and 6). It contains other



segregation pegmatites composed mainly or entirely of plagioclase  $\pm$  quartz and bordered by mafic extraction zones. This type of segregation pegmatite (c.f. Fig. 7), which is also seen in Ameralik dikes at locality 2.7, developed under amphibolite facies conditions.

A thicker, more typical Ameralik dike is separated from the western contact of the ferrodiorite by a thin slice of grey gneiss. It was misidentified by Berthelsen as an apophysis of the diorite. To the west there are typical Amîtsoq layered grey gneisses that inland border a raft of layered ultramafic rocks (Akilia association). Around the point to the west they are in contact with rather massive Amîtsoq augen gneiss from which Ameralik dikes are absent. It is unusual, outside the Isukasia area, to find a section of Amîtsoq gneisses as thick as this with no Ameralik dikes.

#### Locality 2.6: Ingerssuartût

A wide range of supracrustal and intrusive basic and ultrabasic rocks belonging to the Akilia association are exposed on this group of islands (Fig. 23). An unusually thick, layered Ameralik dike crops out on the eastern and southern islands, but elsewhere there are only a few thin Ameralik dikes.

An early layered sequence includes banded iron formation (with combinations of quartz, magnetite, grunerite, Fe-rich orthopyroxene, clinopyroxene, garnet,

actinolite and sulphides) and layered amphibolites with subordinate ultramafic rocks, quartz-biotite-sulphide gneisses, felsic gneisses and clinopyroxenites. The layered amphibolites and metasediments are interlayered on scales of less than 1 meter to more than 50 meters. In places there is evidence of secondary silica penetration of the layered rocks. The chemistry of the best preserved amphibolites suggests that they are predominantly of Archean picritic to Fe-tholeiitic affinity.

The layered sequence is cut by thick, locally discordant bodies of leuco-amphibolite that are weakly laminated in places. They have geochemical affinities with some strongly fractionated komatiitic liquid compositions.

Relic cores with early Archean granulite facies mineral assemblages are preserved locally, for example in layered basic rocks on the low island south-east of the largest island and connected to it at low tide, and in banded iron formation on the south-west coast of the largest island. The thick Ameralik dike on the eastern and southern islands has garnet-bearing, higher grade cores, but has not been found to contain orthopyroxene. It thus appears to post-date the granulite facies metamorphism.

There are thin, post-Ameralik dike sheets of grey gneiss on the northern part of the largest island and many little- or undeformed sheets of biotite-bearing pegmatite and microgranite that here, as elsewhere in the Qilángârssuit area, commonly trend E-W.

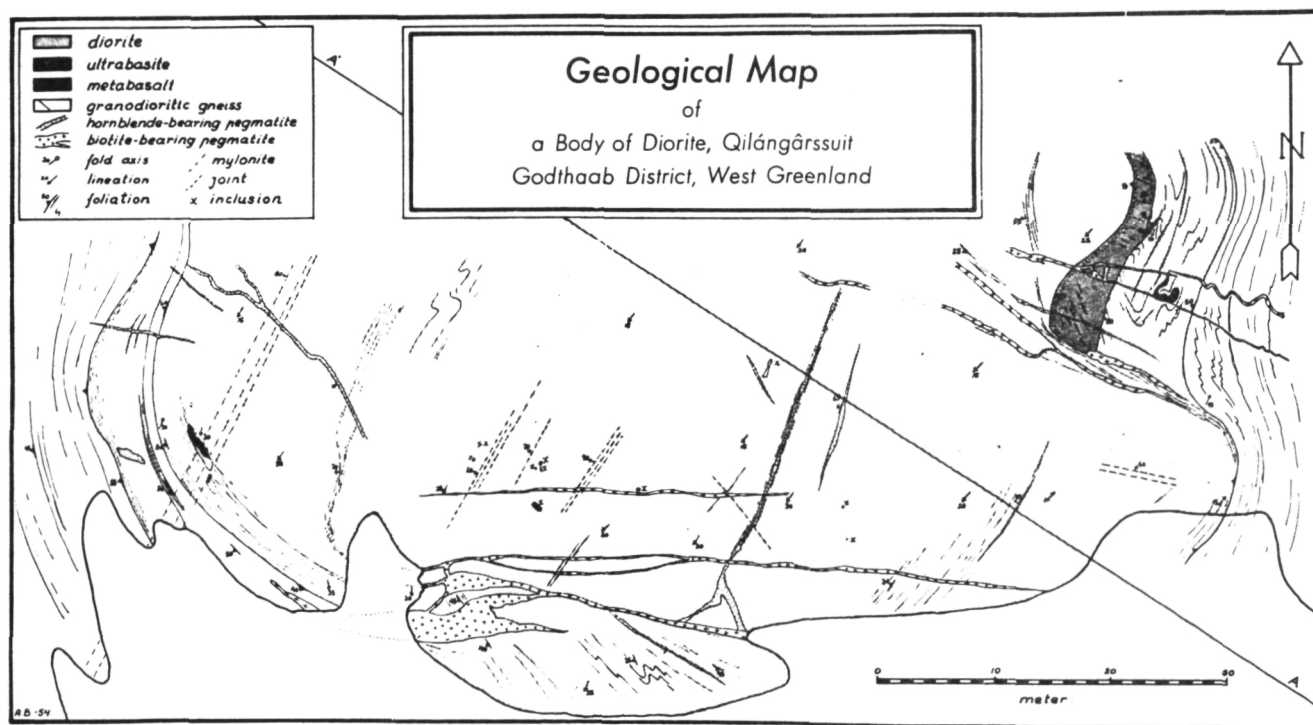


Fig. 22. From Berthelsen (1955).



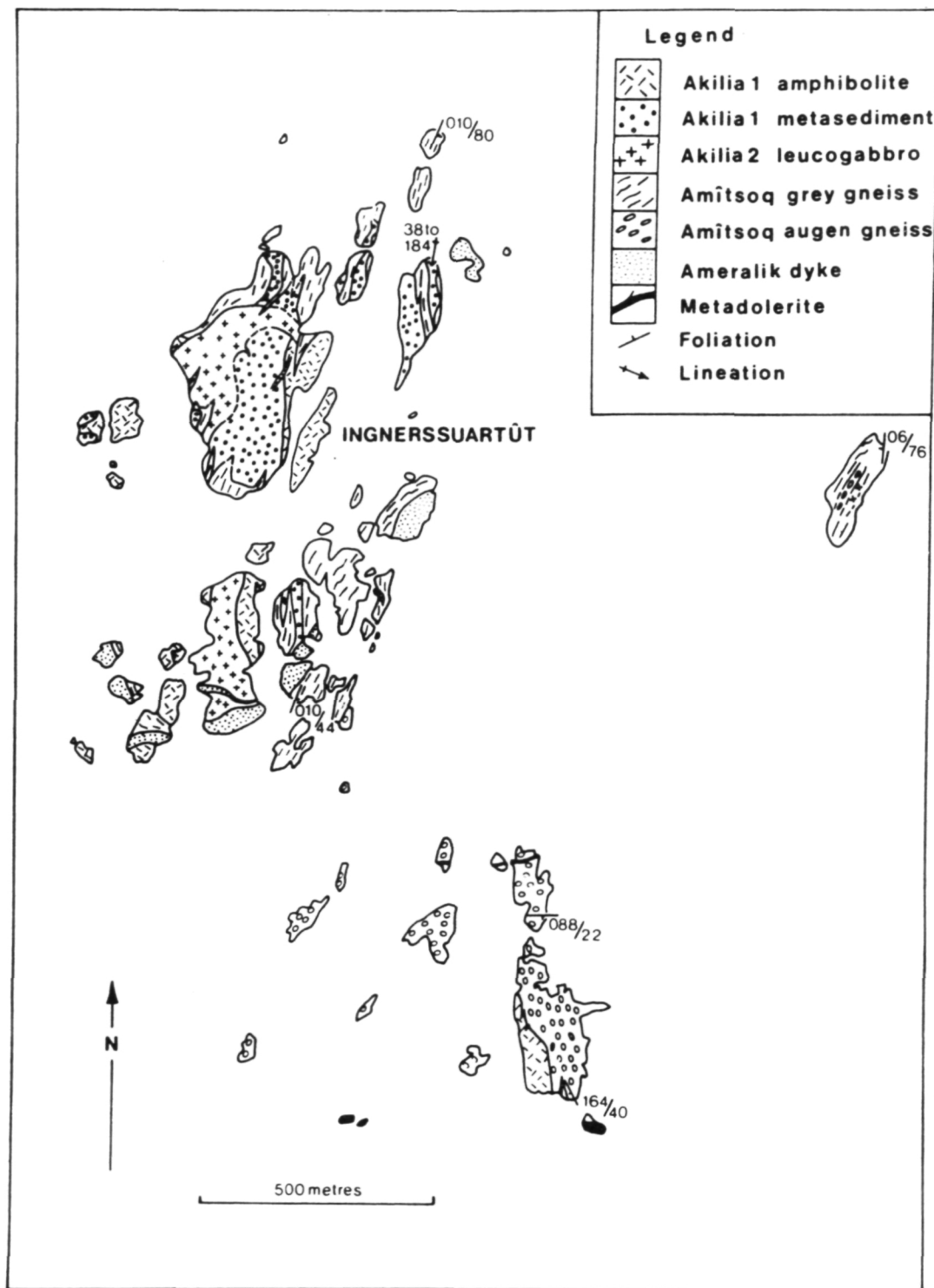


Fig. 23. Geological map of Ingnerssuartût and nearby islands, from Griffin et al. (1980).

### Locality 2.7: Island Between Ingnerssuartût and Qilángárssuit

At this locality Amîtsoq gneisses and Akilia basic rocks, which are in an area of unusually low late Archean deformation in the core of a synform, preserve textural evidence of early Archean granulite facies metamorphism.

Because of the low deformation, most Ameralik dikes at this locality are still clearly discordant. There are several types that range from ultramafic to leucoamphibolite in composition. Some dikes contain very scattered, small plagioclase megacrysts. On the south side of the island a homogeneous mesocratic Ameralik dike is cut by a rusty-weathering leucocratic Ameralik dike with many pegmatitic segregations. Both dikes are strongly discordant to the layering in the gneisses. At the western end of the island there is a strongly folded, broken-up ultramafic dike and nearby a thicker dike with a pattern of segregation pegmatites. The segregation pegmatites in Ameralik dikes at this locality are all of the type with leucocratic cores that formed under amphibolite facies conditions (see locality 2.5). Note the relatively wide spacing of Ameralik dikes at this locality compared with more typical Amîtsoq gneiss exposures seen elsewhere, where strong late Archean deformation has telescoped together and thinned the originally more widely spaced, thicker Ameralik dikes. The Ameralik dikes here are totally recrystallized to lineated hornblende amphibolites, showing that all the rocks at this locality recrystallized under middle-upper amphibolite facies conditions in the late Archean.

Nonetheless, because of the low degree of late Archean flattening deformation, early Archean textural features that indicate recrystallization under granulite facies conditions are preserved locally. The polyphase, pegmatite-streaked, grey gneisses have patches with clear relic blebby texture, spotty pegmatitic areas and big-hornblende pegmatites, features comparable to those seen in areas retrogressed from late Archean granulite facies metamorphism (localities 2.10 and 3.3). These features are truncated at the discordant margins of Ameralik dikes, and it can be seen that the relic granulite facies textures were deformed before the Ameralik dikes were intruded. There are abundant mafic pegmatites and ultramafic segregations, both indicators of previous granulite facies recrystallization, in rafts of layered Akilia amphibolites. Comparable features are absent from the Ameralik dike amphibolites. This is clear evidence that the Ameralik dikes here post-date the granulite facies metamorphism, which must therefore have occurred in the early Archean. Near the western end of the island there is a large raft of Akilia metagabbro that is cut by a discordant Ameralik dike.

There are a few zones, e.g., near the western end of the island, where the degree of late Archean flattening deformation is greater. Note how the Amîtsoq gneisses in these zones take on a rather simple, regularly layered appearance. It is clear that both early- and late-Archean deformation must have erased the complex early history of the Amîtsoq gneisses in most places. As a general rule, the layered grey gneisses that form much of the Amîtsoq gneisses cannot be used to provide *detailed* information on the nature of early Archean crust formation.

### Locality 2.8: Simiútat

Malene supracrustal rocks, especially metasedimentary gneisses, are more varied and better exposed on this group of islands than anywhere else in the region. The geology of the islands is shown on Fig. 24, which has been drawn for this excursion guide by Dr. Brian Chadwick, University of Exeter.

We visit a locality where Malene quartz-cordierite-anthophyllite-sillimanite gneisses are well exposed. The very unusual composition of this lithology is shown by analysis 131490, Table 4, of a specimen from the same unit on Sagdlerssua, an island just to the northwest. More analytical data can be found in Beech and Chadwick (1980). Dymek (1983) has shown that the rutile in this lithology is unusually rich in Nb. In places it can be seen with the naked eye. Cordierite, anthophyllite and sillimanite can be found as very large grains. It is clear from the geological relations of the unit here that the rock cannot be the product of local metasomatic action, but must have been laid down as a thick, extensive unit in the supracrustal sequence. Note also the complete lack of any amphibolites of Ameralik dike type. The unit contains lenses rich in garnet that locally enclose relics of staurolite.

### Localities 2.9-2.12: Kangerdluarssoruseq (Færingehavn fjord)

At these localities (Fig. 25) we see early Archean rocks on both sides of the late Archean prograde granulite-amphibolite facies boundary. The granulite facies mineral assemblages have been almost totally retrogressed to amphibolite facies, but the rocks retain textural features that were developed under granulite facies conditions. They have been affected by strong post-granulite facies deformation that included major folding and the development of a late "straight belt" of intense ductile deformation similar to the deformation belt through Nuuk town. The rocks on the amphibolite facies (western) side of the metamorphic facies boundary were intruded by late granitic ("white gneiss") and pegmatitic sheets that may well have been generated by anatexis of rocks

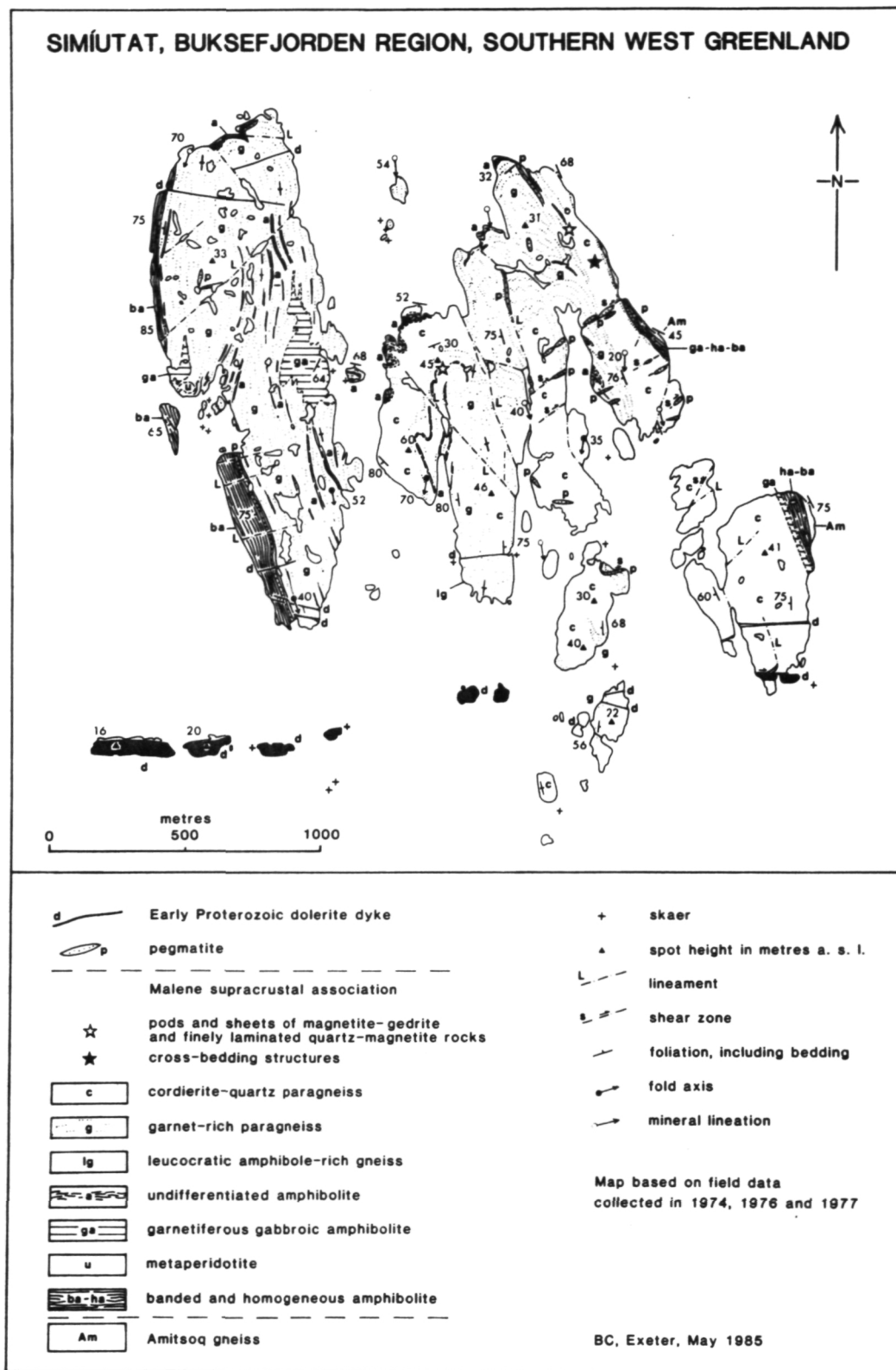


Fig. 24. Geological map of Simiútát drawn by Dr. Brian Chadwick, University of Exeter.

enriched in elements expelled from deeper levels that suffered granulite facies metamorphism. The late granitic rocks were affected by the "straight belt" deformation.

**Locality 2.9:**

Relic cores in a migmatized basic unit of uncertain but probable Akilia affinity contain abundant orthopyroxene, together with hornblende, especially in mafic pegmatites and ultramafic segregations. They can be

followed through rocks in which orthopyroxene is progressively replaced, first by fibrous brown amphibole and then by black hornblende, into adjacent amphibolites that are totally retrogressed to amphibolite facies. The gneisses that intrude the basic rocks preserve clear blebby texture locally in low deformation areas, but have mainly suffered very intense deformation that destroyed textural evidence of granulite facies metamorphism.

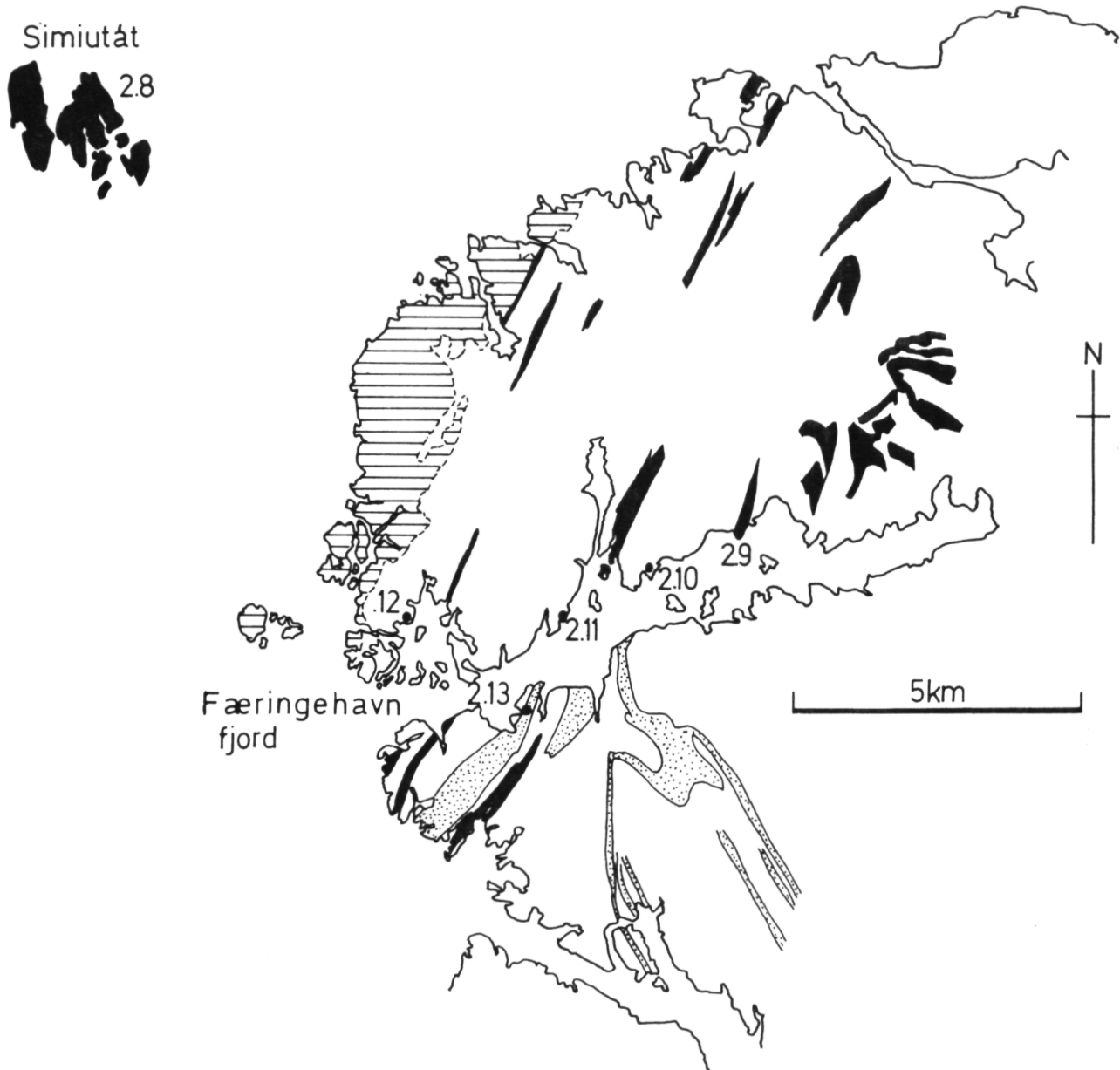


Fig. 25. Excursion localities in Kangerdluarssoruseq. Geology from 1:100,000 Buksefjorden map sheet. Black = supracrustal and basic rocks; dotted = anorthositic rocks; ruled = late granitic gneisses and pegmatites.

**Locality 2.10:**

Amîtsoq gneisses with relatively unbroken Ameralik dike amphibolites contain abundant textural evidence of late Archean granulite facies metamorphism:

1. pervasive blebby texture in the gneisses,
2. most of the layered structure in the gneisses has been lost and the gneisses have become nebulitic,
3. mafic pegmatites and ultramafic segregations in Ameralik dikes,
4. relic orthopyroxene or fibrous, brown amphibole secondary after orthopyroxene.

From this locality we walk along the coast towards the west and observe how textural indications of granulite facies metamorphism in the Amîtsoq gneisses and the common, thin sheets of Ameralik dike-type amphibolite have been modified by strong "straight belt" deformation.

**Locality 2.11: Nordafar**

The rocks at Nordafar appear to be just outside the original prograde granulite facies boundary, but relations are complicated by late deformation.

On the coast just west of the Seamen's Home, Amîtsoq gneisses with Akilia association lithologies that include striped green-and-black clinopyroxene-hornblende rock are cut by clearly discordant Ameralik dike amphibolites, several of which contain the characteristic plagioclase clots. The rocks are cut by late white gneiss-pegmatite sheets. There is scattered blebby texture in the gneisses, especially in more mafic areas, but no evidence of previous granulite facies metamorphism in the Ameralik dikes (no mafic pegmatites or ultramafic segregations). This situation (textural evidence of previous granulite facies metamorphism in Amîtsoq gneisses, but none in enclosed Ameralik dikes) holds throughout the outer part of Kangerdluarssoruseq and the islands to the south-west, and leads us to conclude that the blebby texture in the gneisses dates from the early Archean and not the late Archean granulite facies metamorphism.

Eight Amîtsoq gneisses from this locality yield a poorly correlated Rb/Sr whole rock isochron with an age of  $3001^{+193}_{-153}$  Ma. Nd isotopic data for 3 of the specimens lie within the scatter for the type Amîtsoq gneisses. They yield model ages of between 3400 and 3200 Ma (Collerson et al., this volume).

Eastward the sequence seen on the coast around the bay and near the wharf is:

1. Amîtsoq gneisses as described above.
2. A thin mylonite and pegmatites near the contact to (3).
3. A thin unit of pale, well-layered Malene amphibolite, strongly affected by late deformation.
4. Garnet-bearing Malene metasedimentary gneisses, including quartz-cordierite gneisses.

5. A thin unit of Amîtsoq gneisses with thin, unbroken Ameralik dikes.

6. Rather homogeneous gneiss of Nûk-type.

7. Interlayered amphibolite and metasedimentary gneisses, including a homogeneous amphibolite with granulite facies-type mafic pegmatites.

8. Layered garnet-bearing amphibolite, probably derived from a gabbroic marginal phase of the anorthosite complex.

9. Leucogabbroic schist.

10. Garnet-bearing Malene metasedimentary gneisses with thin amphibolites.

11. Polyphase, relatively homogeneous, Nûk-type gneisses.

On the island just east of the wharf there are Amîtsoq gneisses with Ameralik dikes and layered basic rocks belonging to the marginal phases of the anorthosite complex. In all of these rocks there is abundant textural evidence of late Archean granulite facies metamorphism, as seen at locality 2.11, although the rocks now have amphibolite facies mineral assemblages. The granulite-amphibolite facies boundary must be within the strongly deformed section through the Nordafar wharf. Elsewhere in this area it can be seen to be tectonic.

**Locality 2.12: Old Færingehavn**

Early Archean rocks intruded by late pegmatites and white gneisses are all affected by very strong "straight belt" deformation. This makes the distinction between early and late Archean rocks rather uncertain, a common situation in this region. There are a number of clearly recognizable Ameralik dikes with abundant plagioclase clots. There are also layered basic rocks that contain granulite facies-type mafic pegmatites. They are thus probably early Archean (Akilia association).

The white gneisses and pegmatites here appear to be the same association as the rocks to the west that are shown as Qôrqt granite on the Buksefjorden 1:100,000 map sheet. These are, however, probably older than the type Qôrqt granite, which post-dates all major ductile deformation. We have been unable to find the thrust shown on the 1:100,000 map sheet. It is drawn through a section where the geology appears to be continuous and where there is an increase in the proportion of pegmatite to white gneiss and a decrease in the intensity of late deformation.

**Locality 2.13: Polarøil**

At this stop we see a typical unit of mid-Archean leucogabbro-anorthosite, a lithology that is widespread throughout the region and forms useful structural markers.

From the west, at the boundary fence of the oil depot, we traverse pegmatite-streaked quartzofeldspathic



gneisses with highly attenuated, migmatized rafts of amphibolite derived from the gabbroic marginal phases of the anorthosite complex. There is no textural evidence to suggest that the gneisses have been retrogressed from granulite facies. Toward the massive leucogabbroic rocks there are discontinuous layers of garnetiferous gneisses that may be metasediments or alternatively may be products of interaction between the metagabbros and the intrusive gneisses.

The anorthositic unit is made up of interlayered, rather fine-grained leucogabbro and anorthosite with subordinate mafic gabbro. All the rocks have probably suffered total metamorphic recrystallization and have been severely flattened and attenuated by straight-belt deformation. This anorthosite locality is situated near the margin of an eye of low strain within the deformation belt. Local graded layering occurs, which indicates that the unit is inverted. This is in accord with the direction of younging observed in the area of lower strain a little to the south.

Table 4. Analyses of Rocks Seen On Excursion 2.

	155734	131490	162475	243057c
SiO <sub>2</sub>	53.06	72.46	61.56	87.80
TiO <sub>2</sub>	2.26	0.24	1.32	0.08
Al <sub>2</sub> O <sub>3</sub>	13.63	14.85	13.89	6.32
FeO <sup>t</sup>	13.54	2.97	8.19	0.10*
MnO	0.20	0.02	na	nd
MgO	2.75	6.94	1.38	0.02
CaO	7.46	0.09	4.26	0.01
Na <sub>2</sub> O	3.07	0.3	3.26	0.61
K <sub>2</sub> O	1.06	0.13	2.87	4.50
P <sub>2</sub> O <sub>5</sub>	0.36	0.03	0.52	0.02
LOI	<u>0.61</u>	<u>0.70</u>	<u>0.43</u>	<u>0.14</u>
Total	98.00	98.73	97.68	99.61
Rb	12	28	105	99
Sr	286	3	148	37
Ba	510	7	145	561
Zn	130	49	na	na
Y	34	185	84	11
Zr	155	545	606	142
Pb	9	2	na	14
Nb	10	60	na	na
Cr	55	25	na	21
Co	37	11	na	na
Ni	15	4	na	nd

na = not analyzed; nd = not detected; \* as FeO.

155734: ferrodioritic gneiss, SE Qilángarsuit

131490: quartz-cordierite gneiss, Sagdlerssua (same unit as that on Simiútat).

162475: Amítoq augen gneiss, Kanajorssuit.

243057c: quartzite, Simiutå.

## EXCURSION 3

### NUUK — AMERALIK — NUUK

The eastern contact zone of the "main body" of the Qôrqt granite complex is well seen on the mountains on the north side of Ameralik. Type Amítoq gneisses with very large rafts of Akilia association basic and other lithologies are cut by a plexus of sub-horizontal sheets of granite and pegmatite. A very thick sheet of layered aplite-pegmatite can be seen capping the eastern end of the mountain Qáqarssuaq. The amount of rafts of country rocks decreases eastwards into the granite, but the sub-horizontal sheeted structure of the complex is still evident.

#### Locality 3.1: Coast Below Inugssugssuaq

Here we will see Amítoq gneisses in what may be the zone enriched in elements expelled from deeper rocks affected by late Archean granulite facies metamorphism. No specimens from this locality have been analyzed. The rocks have a distinctive pinkish color that is unusual for the region. Most outcrops of Amítoq gneisses appear grey when viewed from a distance. There are numerous Ameralik dike amphibolites, some strongly broken-up and others more continuous. The gneisses contain granitic layers, both modified early layering and discordant veins, as well as pegmatitic veins bordered by biotite-rich zones. These structures may represent the beginning of melting. The rocks are folded and have a pervasive SSE-plunging fabric element that post-dates granite formation. This linear fabric is not present in strongly discordant pegmatite and granite sheets that are of Qôrqt granite type. The melting episode seen here was thus separated from the intrusion of the Qôrqt granite and pegmatite sheets by the deformation episode that formed the linear fabric. This linear fabric occurs throughout the outer part of Ameralik and may be the same age as the late deformation belt through Nuuk town.

#### Locality 3.2: Nipínganeq

A large body of mafic tonalitic gneiss (analysis 217390, Table 5) occupies the core of a major synform. The central part of the body has been affected by only relatively weak deformation. It does not contain Ameralik dike-type amphibolites and is interpreted as an early phase of the Nûk gneisses.

In exposures on the north coast of Ameralik the tonalitic gneiss has pervasive blebby texture and encloses many big-hornblende pegmatites of the type that elsewhere is seen to have developed during granulite facies metamorphism. These features indicate that the tonalitic gneiss was affected by late Archean granulite facies metamor-

phism, but was later totally retrogressed to amphibolite facies. Intense deformation on both limbs of the synform has erased most textural evidence of granulite facies metamorphism.

Nipínganeq tonalitic gneiss crops out east of the unit of early Archean rocks on Kangimut sangmissoq and in a very attenuated state just outside the leucogabbroic "membrane" of the Inugssugssuaq structure (see Locality 3.4). In these areas too, there is abundant textural evidence that it has been retrogressed from granulite facies. Metamorphosed tabular bodies of amphibolite of Ameralik dike type are absent.

The tonalitic gneiss is cut by many irregular, composite bodies of pegmatite-granitic gneiss that post-date granulite facies metamorphism. They were emplaced along active movement zones and developed a primary gneissic structure as they crystallized. Six samples yielded a Rb/Sr whole rock isochron age of  $2692 \pm 62$  Ma with  $Sr_i = 0.7060 \pm 0.0015$  (Roberts, 1979). The youngest rocks in these exposures are sub-horizontal pegmatite sheets belonging to the Qôrqt granite complex.

Four specimens of the tonalitic gneiss yielded a Rb/Sr whole rock isochron age of  $2514 \pm 50$  Ma with  $Sr_i = 0.7028 \pm 0.0005$  (Roberts, 1979). This cannot be the age of intrusion of the tonalite and is interpreted as the result of Rb introduction associated with the intrusion of the Qôrqt granite complex. It is probable that the tonalite had been depleted in Rb during granulite facies metamorphism.

### Locality 3.3: Kangimut sangmissoq

This is the most controversial, but perhaps also the most important locality to be visited during the workshop. Rocks that have clearly been retrogressed from (late Archean) granulite facies have the field characteristics of early Archean Amítoq gneisses and Ameralik dikes. However the gneisses have Rb/Sr, Pb/Pb and Sm/Nd characteristics that are considered by Jones, Moorbath and Taylor (this volume) to indicate derivation from a mantle source in the late Archean. We consider that these gneisses are dominantly early Archean in age and that the isotopic systems in them were severely disturbed during late Archean granulite facies metamorphism.

The locality (Fig. 26) is near the eastern edge of a unit of Amítoq-type gneisses that lies within the core of the same broad, south- to southeast-plunging synclinorium as the Nipínganeq tonalitic gneiss. Nipínganeq (Nûk) tonalitic gneiss crops out on the coast to the east, only a short distance across strike. Both the Nûk tonalitic gneiss and the gneisses at this locality have pervasive blebby texture. Throughout the Kangimut sangmissoq unit the gneisses enclose abundant tabular bodies of amphibolite

of Ameralik dike type. A number of these amphibolites contain trains or scattered clots of calcic plagioclase. There can be little doubt that these amphibolites are derived from basic dikes indistinguishable from the type Ameralik dikes, but their original discordant relations to the gneisses have been erased by deformation and subsequent recrystallization under granulite facies conditions. Mafic pegmatites are common within the amphibolites. Toward the northern end of the outcrop there is a 20-25-m-thick body of well-layered basic rock that has a 2-m-thick zone with abundant large plagioclase clots. Relic cores in this body preserve granulite facies mineral assemblages (specimen 152765, Table 2 and Fig. 4 in Griffin et al., 1980). We interpret this body as an unusually thick Ameralik dike. Thick Ameralik dikes with similar layering have been observed elsewhere in the region.

A number of the metamorphosed basic dikes have been migmatized along their contacts, but are still continuous. Others have been split into sub-parallel slices by granitic material emplaced parallel to their margins. Locally the dikes have been completely broken up and occur as separated fragments "floating" in the gneisses. Amphibolites derived from basic dikes are completely absent from the Nûk tonalitic gneiss to the east.

The gneisses in the Kangimut sangmissoq unit are variable, coarse-textured and nebulitic. In places the mafic spots that give the blebby texture are open clusters of coarse-grained biotite, garnet, hornblende and opaque minerals. Elsewhere they are polygranular aggregates of hornblende with a little biotite. The gneisses are tonalitic to trondhjemitic in composition (analyses 152755, 152757, Table 3; see also Nutman et al., this volume). They contain little-deformed big-hornblende pegmatites, in some of which the large hornblendes have cores of cummingtonite and quartz that locally contain relic orthopyroxene.

The migmatization and break-up of some of the metamorphosed basic dikes shows that the gneisses must contain some material that is post-basic dike, but pre- or syn-granulite facies metamorphism. Recrystallization under granulite facies conditions (textural homogenization) has blurred or erased contacts between this material and the earlier gneisses. It is thus quite possible that the samples used for isotopic studies include some Nûk material. However, the abundance of relatively unbroken amphibolites of basic dike type, which is comparable to the abundance of Ameralik dikes in typical unmigmatized Amítoq gneisses elsewhere, indicates that the gneisses here must be dominantly older than the basic dikes.

Thin, composite dikes and veins of granitic gneiss and pegmatite post-date the granulite facies metamorphism and were intruded along movement zones. Four specimens give a Rb/Sr whole rock isochron age of  $2680 \pm 180$

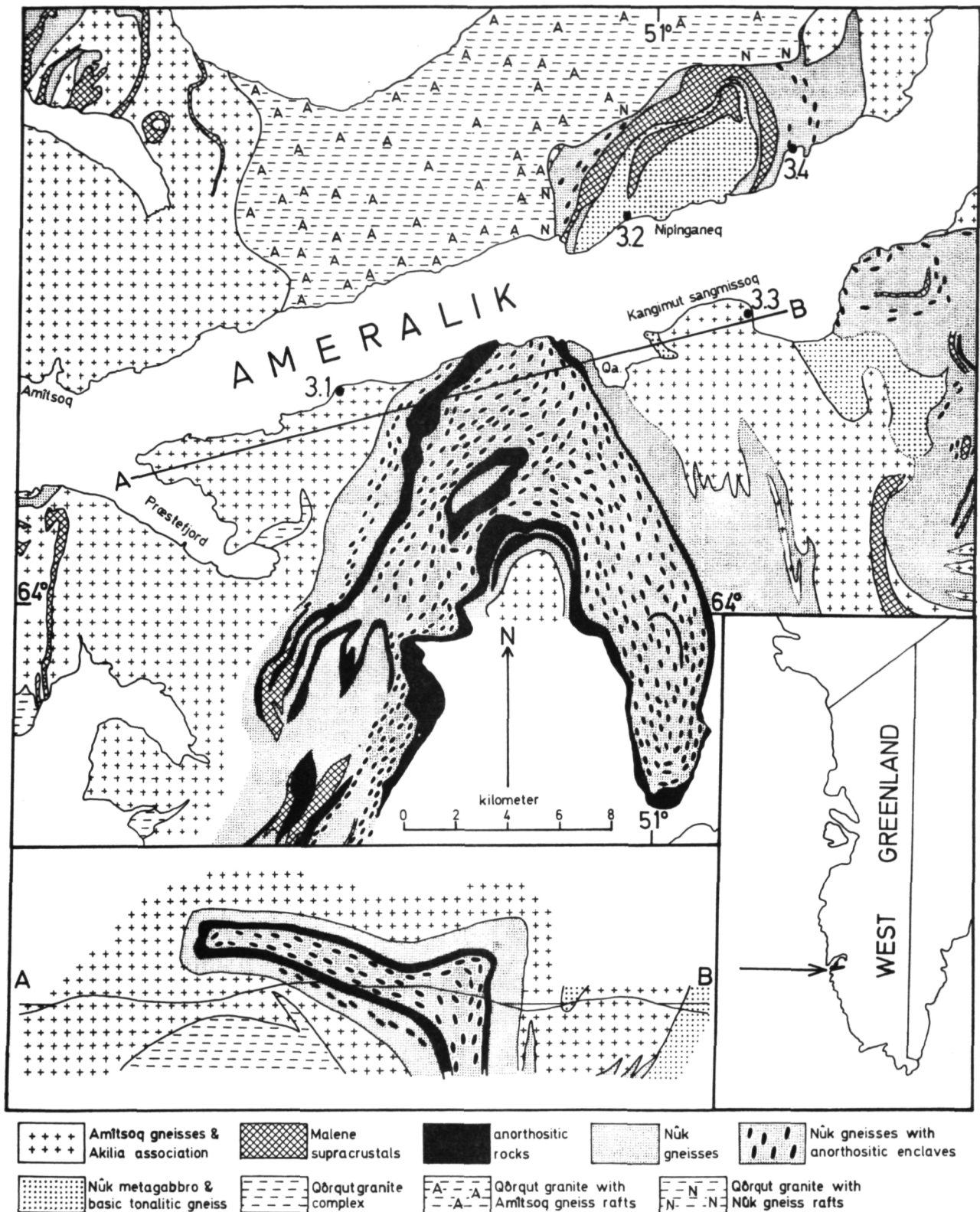


Fig. 26. Geological sketch map of central Ameralik.

Ma with  $Sr_i = 0.7045 \pm 0.0010$  (S. Moorbath, pers. comm.). The field and isotopic characters of these dikes indicate that they are the same generation as the late, composite dikes that cut the Nipínganeq tonalitic gneiss at the last locality. A rusty layer about half-way along the outcrop, composed of plagioclase, quartz and pale brown mica with smaller amounts of sulphides, sphene, epidote and apatite, may be a late intrusive sheet.

Suites of specimens were collected as Amítsoq gneisses retrogressed from granulite facies by V.R.M. and Dr. Stephen Moorbath from this locality and from the western part of the same Amítsoq gneiss unit at Qasigiánguit, as well as from the tonalitic Nûk gneiss to the east, in 1976 and 1977. Isotopic results are reported for these specimens by Jones, Moorbath and Taylor (this volume).

1. Rb/Sr: Six gneisses retrogressed from granulite facies define a  $2770 \pm 185$  Ma isochron with  $Sr_i = 0.70195 \pm 0.00054$ .

2. Pb/Pb: The pattern of Pb isotopes in 18 samples is analogous to the pattern in Nûk gneisses within the belt through Godthåbsfjord that was not affected by late Archean granulite facies metamorphism (Taylor et al., 1980). The Kangimut sangmissoq gneisses show evidence for contamination with Amítsoq-type Pb, but few show severe contamination effects, and most have a very large proportion of their initial Pb from a juvenile source at ca. 2770 Ma.

3. Sm/Nd: Six gneiss samples define a  $2825 \pm 125$  Ma isochron with  $\epsilon_{Nd(1)} = +2.2$ .

Rb/Sr and Sm/Nd data on a further suite of gneisses collected from this unit in 1980 are reported by Collerson et al. (this volume).

Zircons from a single gneiss specimen from this locality have been analyzed by Professor H. Baadsgaard (pers. comm.). The datum point lies on the lower part of the same discordia line on a U/Pb plot as Akilia association zircons (Baadsgaard et al., 1984). Akilia zircons that plot near the lower end of this discordia line are from outcrops close to the main body of the Qôrqt granite complex, the eastern contact of which is only 5 km from this locality. The  $^{207}\text{Pb}/^{208}\text{Pb}$  age is 2830 Ma.

The field evidence that the rocks at this locality are dominantly early Archean Amítsoq gneisses is:

1. The presence of abundant bodies of amphibolite identical to Ameralik dikes in the type Amítsoq gneisses only 10 km to the west of this unit. It is most unlikely that these could be intra- or post-Nûk dikes since comparable dikes are completely absent from adjacent Nûk gneiss units, including the Nipínganeq tonalitic gneiss.

2. The continuity of the geology from the type Amítsoq gneisses in outer Ameralik and Præstefjord, which

preserve early Archean isotopic characteristics, through the whole length of Ameralik and east as far as our personal knowledge of the geology extends.

Throughout this section Amítsoq gneisses, like those at this locality, alternate with units of younger rocks from which Ameralik dike-type amphibolites are absent. A structural reconstruction (Fig. 26, cross section; see also locality 3.4) indicates that the Kangimut sangmissoq gneisses are the same major unit as the type Ameralik gneisses in outer Ameralik.

### Locality 3.4: Naujánguit

At this locality we see post-granulite facies, granodioritic gneisses with enclaves of anorthositic lithologies.

On the south side of Ameralik the type Amítsoq gneisses are separated from the Kangimut sangmissoq unit by Nûk gneisses that enclose two continuous units and abundant enclaves of anorthositic rocks. Stainforth (1977) and Chadwick et al. (1982) interpreted this as a major magmatic nappe structure, the Inugssugssuaq (Inussus-suaq in the new orthography) nappe, in which a "membrane" of anorthositic rocks was blown up like a balloon by granodioritic Nûk magmas that crystallized to form the gneisses with abundant anorthositic enclaves in the core of the structure. The hinge of the nappe is not exposed in the ground mapped by Stainforth, but was considered to be exposed within the late deformation belt north of the mouth of Buksefjorden. Graded igneous layering in the anorthositic units faces outwards in opposite directions on the limbs of the structure, indicating an isoclinal fold. Stainforth's interpretation of the structure is incorporated into the cross section in Fig. 26. We have reservations about this interpretation and consider it even possible that the granodioritic gneiss was intruded as a thick sheet into the anorthositic unit *after* it had been isoclinally folded. The same unit of granodioritic gneiss with abundant anorthositic enclaves appears to extend from south of Færingehavn through central and inner Ameralik and into Godthåbsfjord at least as far as the northern part of Storø.

The lithologies of the Inugssugssuaq structure extend across Ameralik, are folded around the Nipínganeq synform, and reappear on the coast at Naujánguit. There is no blebby texture or other evidence of previous granulite facies metamorphism in the granodioritic gneiss with anorthositic enclaves here or in the core of the Inugssugssuaq structure. We conclude that the granodiorite was intruded after the late Archean granulite facies metamorphism, and that the Inugssugssuaq structure and the open folds that re-fold it, including the Nipínganeq synform, are thus also post-granulite facies.



Table 5. Analyses of Rocks Seen On Excursion 3.

	217390	152755	152757
SiO <sub>2</sub>	62.70	66.54	69.02
TiO <sub>2</sub>	0.60	0.65	0.38
Al <sub>2</sub> O <sub>3</sub>	16.50	16.02	15.52
FeO <sup>i</sup>	5.54	4.45	3.30
MnO	0.09	na	na
MgO	2.25	1.39	0.95
CaO	5.62	5.13	4.20
Na <sub>2</sub> O	4.40	3.85	3.99
K <sub>2</sub> O	0.85	0.43	0.94
P <sub>2</sub> O <sub>5</sub>	0.14	0.12	0.08
LOI	na	0.63	0.56
Total	98.69	99.21	98.94
Rb	15		
Sr	236		
Zn	64		
Y	13		
Zr	152		
Co	44		
Ni	24		

na = not analyzed.

217390: tonalitic gneiss, Nipínganeq (Roberts, 1979).

152755, 152757: Kangimut sangmissoq gneisses.

## EXCURSION 4

### NUUK — QÔRQUT

Localities for Excursion 4 are shown in Fig. 27.

#### Locality 4.1: Máluto

At this stop we will see rocks affected by 3000-2950 Ma granulite facies metamorphism on the east coast of Nordlandet.

On the north coast of the sound between Máluto island and the mainland we see gneisses that are only partly retrogressed from granulite to amphibolite facies. In the retrogressed gneisses, note that there is little blebby texture of the type seen in gneisses retrogressed from early Archean and from ?2800 Ma granulite facies in the southern parts of the region. However there are abundant mafic pegmatites and ultramafic segregations in rafts of mafic rocks. The granulite facies rocks are cut by a sheet of pale weathering, streaky, granodioritic gneiss, one of the Kanásut sheets of Reed (1980). The granodioritic gneiss does not have or appear to have had granulite facies mineral assemblages, yet there is no indication that it retrogressed the granulite facies rocks that it cuts. We suggest that it was intruded under granulite facies conditions, but contained sufficient water to prevent it crystallizing to a granulite facies assemblage. It may be

the product of partial melting under granulite facies conditions in which the granodioritic magma scavenged water from the enclosing rocks.

There has been extensive retrogression to amphibolite facies of rocks in the surrounding outcrops, which weather whitish. In most places the retrogression was static, but locally it appears to have been accompanied by deformation, possibly of the same age as the deformation in the late belt through Nuuk town and the western part of Sadleø and Bjørneøen.

#### Locality 4.2: Qârusup imâ

A broad arching structure can be seen on the south-western part of Bjørneøen. This is one of a row of domal antiforms that includes the Lille Malene antiform (excursion 1). The core of the structure is composed of homogeneous granodioritic gneiss. The western limb of this fold follows the edge of the late deformation belt that extends through Nuuk town.

At the locality visited, the coarse-textured granodioritic gneiss is cut by irregular bodies of finer-textured trondhjemitic gneiss. The contact relations are best seen when the rocks are wet. This was the first locality where V.R.M. noticed discordant, intrusive relations between different gneiss phases, when he and his assistant were sitting on this exposure drying off after a swim in 1966. Earlier that summer he and Professor John Sutton had been shown the section of polyphase Nûk gneisses with rafts of Malene amphibolites and chlorite-rich ultramafic rocks on the coasts of the sound between Bjørneøen and Sadleø. They were told (and they believed) that the gneisses were metasediments derived from greywackes and arkoses interbedded with metavolcanic chlorite schists.

However, nobody is infallible. The trondhjemitic gneiss at this locality was considered by V.R.M. and A.P.N. in 1980 to be a Qârusuk dike (see locality 4.3). We were surprised when zircons from it proved to lie on a 2880 Ma discordia line (specimen 248079, Baadsgaard and McGregor, 1981), showing that it belongs to the type Nûk gneisses. Zircons from the granodioritic gneiss (248078) lie on a 2890 Ma discordia line. An analysis of the granodioritic gneiss (163275) is given in Table 6 and a REE pattern for the same specimen in Fig. 28.

On both sides of this outcrop the gneisses are affected by zones of strong deformation in which intrusive relations have been lost and the granodioritic and trondhjemitic phases have become concordant layers in a regularly layered sequence. In this state of deformation, which is more characteristic of the region than the low deformation areas where discordant relations are preserved, the Nûk gneisses could well be taken to be derived from a layered sedimentary sequence.



### Locality 4.3: South-East Corner of Bjørneøen

Malene supracrustal amphibolites and ultramafic rocks intruded by polyphase Nûk gneisses with late Archean Qârusuk aplitic dikes. This area lies within a belt where the metamorphic grade is lower than elsewhere in the region and the Malene and Nûk rocks are unusually fine-grained. Primary features in all lithologies are better preserved than elsewhere in the region with the exception of the Ivisârtoq and Isukasia areas.

The thick Malene supracrustal unit is made up of variable amphibolites and ultramafic rocks. Around the point to the east there is a very small area with relic conglomeratic (agglomeratic) structure and areas with deformed pillow breccia and pillow lava structures (analysis 131501, Table 7). The western part of the Malene unit is made up of green ultramafic lithologies rich in tremolite and magnesian chlorite. Locally this lithology has relic structures suggesting pillow lavas. The composition (analyses 152771, 152772, Table 7) is very similar to that of Malene komatiitic pillow lavas on Ivisârtoq (Hall, 1980).

The supracrustal unit contains lenses of brown-weathering, olivine-bearing ultramafics. Larger bodies of similar lithologies are abundant in the gneisses to the west.

On the coast west of the supracrustal unit are some of the best outcrops of Nûk gneisses in the region. There is a considerable variety of lithologies that range in composition from dioritic to trondhjemitic, with grey, tonalitic types most abundant. Intrusive relations between gneisses and rafts of supracrustal amphibolite and ultramafic rocks and between Nûk gneiss phases are commonly preserved. An analysis of typical tonalitic gneiss (163222) from these outcrops is given in Table 6 and its REE pattern in Fig. 28. A sample of the dominant tonalitic gneiss (248087) has given a zircon U/Pb concordia intercept date of 3070 Ma (Baadsgaard and McGregor, 1981).

The Nûk gneisses are cut by irregular dikes of fine-grained, greenish-grey aplite belonging to the Qârusuk dikes (McGregor et al., 1983), for which this is the type locality. One of the Qârusuk dikes at this locality has given a U/Pb zircon concordia intersection date of 2660

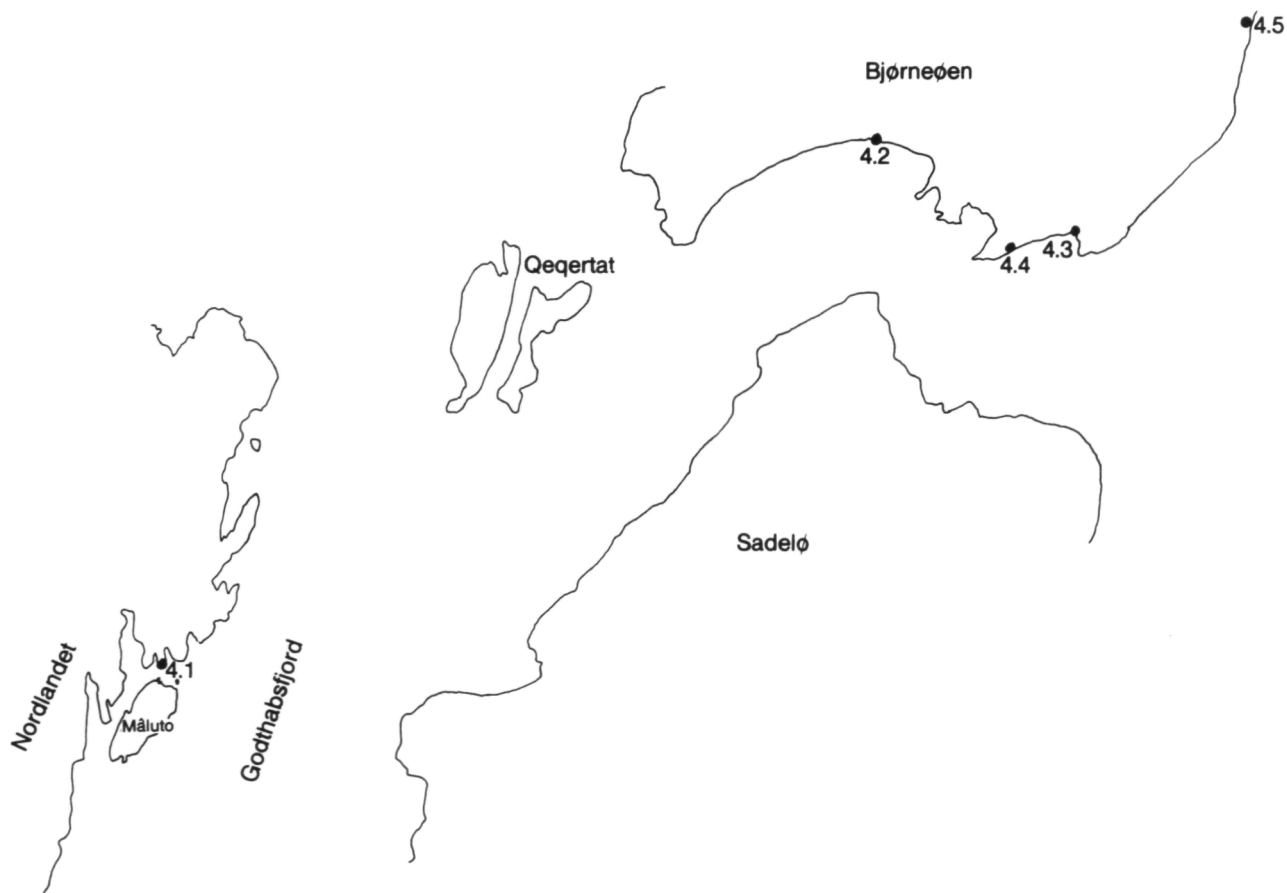


Fig. 27. Locality map for excursion 4.

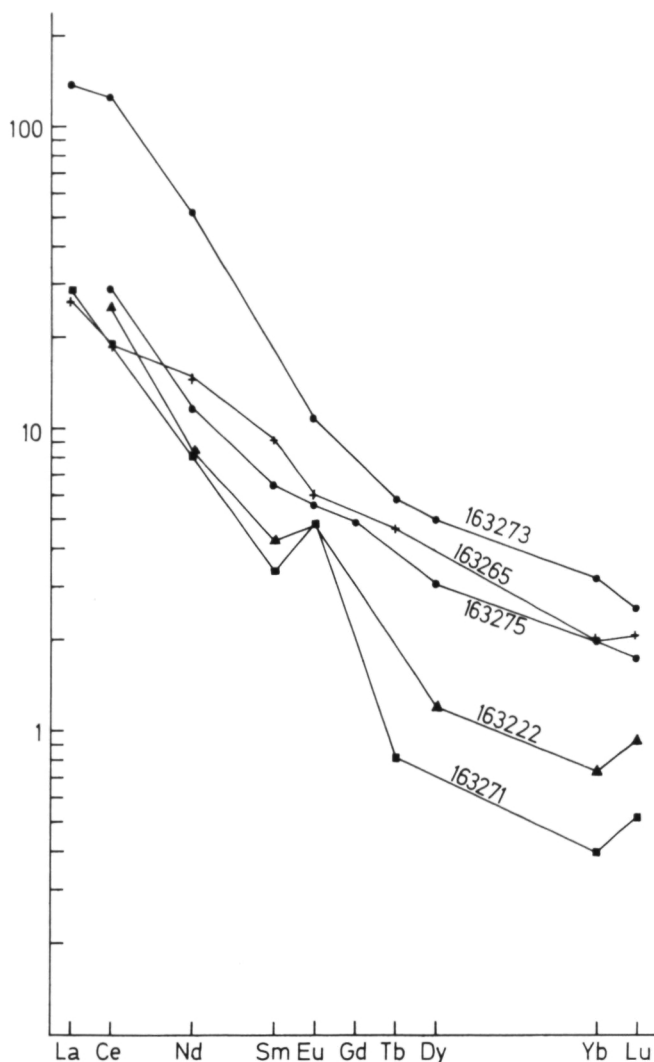


Fig. 28. REE patterns for Nûk gneisses and a Qârusuk dike, southern Bjørnefjorden. Unpublished data from Dr. J.G. Arth, U.S.G.S., Reston.

Ma (Baadsgaard and McGregor, 1981). An analysis of this dike (163273) is given in Table 6 and its REE pattern in Fig. 28. The Qârusuk aplites are finer-grained than the Nûk gneisses they cut. A number of features indicate that they were intruded into active movement zones. Steps in the dike contacts extend out into the country rocks as shear zones. Cataclastic structures occur along some dike margins. Some dikes contain quartz veins with the form of tension gashes. The margins of the least deformed dikes have a bleached appearance that is attributed to movement of fluids along the movement zones into which the Qârusuk magmas were intruded.

Qârusuk dikes from this area (86523, 86536, 86550) were included in suites of Nûk gneisses considered by

Moorbath and Pankhurst (1976) and Taylor et al. (1980; 1984). They have much larger proportions of Amîtsoq-type component in their Pb compared with the enclosing Nûk gneisses and  $T_{\text{CHUR}}^{\text{Nd}}$  model ages of 3200–3660 Ma, suggesting that their source included a significant component of Amîtsoq gneisses or that the magmas or fluids that migrated along the same fractures scavenged Pb, Nd (and Sr) from Amîtsoq gneisses that they passed through.

The Qârusuk aplites appear to be contemporaneous with the very large muscovite-garnet-bearing pegmatites that can be seen in this area. They are assumed to be the same generation as the large pegmatites that cut the Malene unit on Sadleø and Store Malene (excursion 1).

#### Locality: 4.4

On the west side of the bay from locality 4.3, Nûk gneisses are more strongly deformed and intrusive relations are less well preserved. Rafts of Malene amphibolite and ultramafic rocks are cut by several generations of Nûk and Qârusuk veins that deformed more competently than the mica- and chlorite-rich Malene rocks. This resulted in complex interference patterns that may not have much regional significance.

#### Locality 4.5: Naqerdloq kitleq

On the southeast coast of Bjørnefjorden, the Malene amphibolite is structurally underlain by a thick sheet of homogeneous Nûk granodioritic gneiss that can be followed south over eastern Sadleø and along the eastern face of Store Malene. Intrusive relations to the Malene amphibolite are seen as steps in the slightly transgressive contact.

A suite of 11 samples from coastal outcrops of this unit between Ivînguit and Naqerdloq kitleq defines a Rb/Sr whole rock isochron with an age of  $2980 \pm 50$  Ma and  $\text{Sr}_i = 0.7022 \pm 0.0003$ , and a Pb/Pb whole rock isochron age of  $3020 \pm 260$  Ma. The Pb/Pb whole rock isochron is not perfect, but indicates that this unit was “not grossly heterogeneous with respect to initial Pb isotopic composition” (Taylor et al., 1980). An analysis (163265) and a REE pattern are given in Table 4 and Fig. 28.

#### Locality 4.6: South Coast of Storø

The western intrusive contact of the Qôrqt granite complex is well exposed on the mountain face on the southern end of Storø (Fig. 29). The country rocks comprise Amîtsoq gneisses enclosing a unit of black Malene amphibolite. The Malene rocks are broken up by sheets of pale granite that form a sub-rectangular network. This relationship suggests that the rocks into which the Qôrqt granite was intruded acted in a brittle

manner. Few sheets of granite penetrated through the Malene amphibolite into the Amîtsoq gneiss unit to the west. At the very top of the 1000 m cliff, the remains of a unit of Amîtsoq gneisses can be seen east of the Malene unit. Rafts of Amîtsoq gneiss can be discerned as grey, tabular blocks within the paler granite. These rafts have been wedged inwards by granite intruded along their foliation surfaces and thus resemble stoped blocks.

At the base of the cliff the granites comprise both leucocratic and grey granites and contain many locally derived rafts of Amîtsoq gneisses that enclose Ameralik dikes. Some of the leucocratic granite sheets are schlieric and contain a few highly modified gneiss enclaves which are interpreted to have been brought in from the melting zone.

#### Locality 4.7: Qôrqt Hotel

The hotel is situated near the eastern contact of the Qôrqt granite complex. Qôrqt granite with enclaves of country rocks, largely Amîtsoq gneisses, forms the sheer

face of the mountain Qajûta which can be contemplated through the dining room windows. On the 1530 m. mountain NNE of the hotel, sheets of group 3 granites can be seen fingering out laterally into the country rocks. The intermediate and upper zones of the complex (Fig. 11) can be seen on the mountains north of the hotel on the western side of the U-shaped valley of Nigsik.

Table 6. Analyses of Nûk gneisses and a Qârusuk dike from southern Bjørnøen.

	163222	163271	163275	163265	163273
SiO <sub>2</sub>	69.16	72.14	72.20	72.68	71.37
TiO <sub>2</sub>	0.28	0.11	0.20	0.15	0.33
Al <sub>2</sub> O <sub>3</sub>	17.06	16.01	14.92	14.83	14.74
Fe <sub>2</sub> O <sub>3</sub>	0.43	0.07	0.32	0.31	0.25
FeO	1.27	0.76	1.11	0.72	1.64
MnO	0.01	0.02	0.03	0.03	0.02
MgO	0.73	0.29	0.46	0.34	0.47
CaO	3.41	2.65	2.21	2.12	1.80
Na <sub>2</sub> O	5.34	5.50	5.09	4.74	4.14
K <sub>2</sub> O	1.72	1.76	2.35	2.77	4.12
P <sub>2</sub> O <sub>5</sub>	0.04	0.02	0.04	0.04	0.13
LOI	0.43	0.30	0.41	0.49	0.47
Total	99.88	99.63	99.34	99.22	99.48

163222: Dominant grey, tonalitic Nûk gneiss, bay west of Sitdlisît nûat, south-east Bjørnøen, 64° 21.7'N, 51° 20.0'W.

163271: Pale, trondhjemitic gneiss sheet, 2 m. thick, cutting grey, tonalitic Nûk gneiss, Qingordlît, south Bjørnøen 64° 21.7'N, 51° 21.8'W.

163275: Homogeneous, granodioritic Nûk gneiss in core of antiform, Qârusup imâ, south Bjørnøen 64° 22.7'N, 51° 24.0'W.

163265: Homogeneous, granodioritic Nûk gneiss, southeast coast of Bjørnøen between Ívnguit and Naqerdlôq kitdleq, 64° 23.9'N, 51° 15.2'W.

163273: Qârusuk aplitic dike cutting folded Nûk grey gneiss, Qingordlît, south Bjørnøen, 64° 21.7'N, 51° 21.8'W.

## EXCURSION 5

### QÔRQT

This excursion is planned to give people the opportunity to stretch their legs and get some feeling of what it is like to do field work on foot in this region. We walk along the coast between the two streams at the head of Qôrqt fjord.

The rocks are a little outside the eastern margin of the Qôrqt granite complex and comprise Amîtsoq gneisses with Ameralik dike amphibolites and rafts of Akilia association, cut by Qôrqt granite and pegmatite. There is relic blebby texture especially in the more mafic Amîtsoq gneisses and in migmatized Akilia rocks, suggesting that these rocks have been retrogressed from granulite facies. There are no indications of previous granulite facies metamorphism in the relatively unbroken Ameralik dikes. This suggests that the Amîtsoq gneisses in this area were affected by early Archean granulite facies metamorphism before intrusion of the Ameralik dikes.

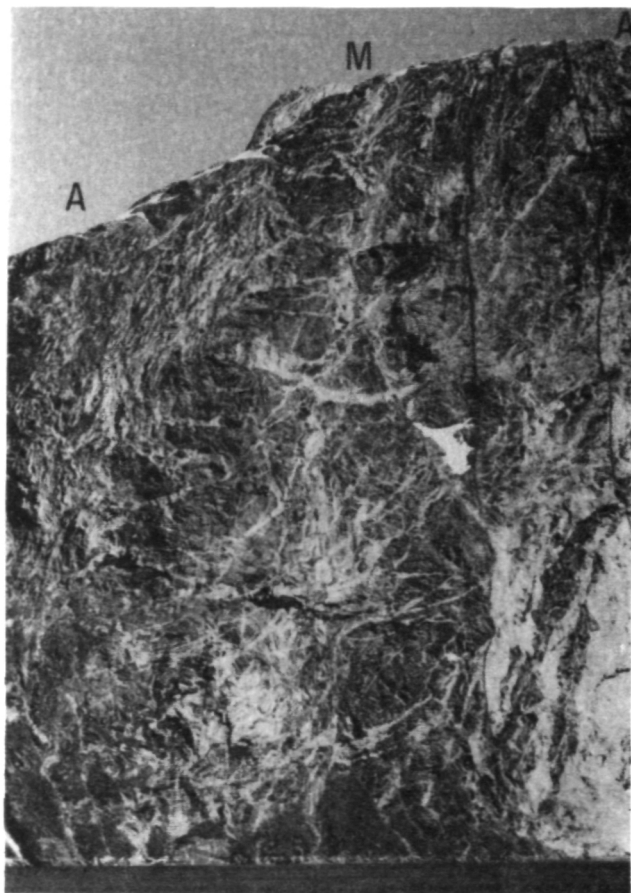


Fig. 29. Intrusive contact of the Qôrqt granite complex on the southern end of Storø. Amîtsoq gneisses are labelled A and Malene amphibolite M.

Amîtsoq gneisses in the first outcrops contain fragments of Ameralik dike amphibolites and enclaves of Akilia ultramafic rocks with zoned reaction rims against the gneisses. Gneisses rich in biotite and hornblende may have been contaminated with material from Akilia ultramafic rocks. Qôrqt lithologies include biotite-magnetite-bearing pegmatites and composite aplite-pegmatite sheets.

On the point about half-way along the outcrop there is a well-layered sequence of Akilia association rocks, mainly amphibolite with hornblende-clinopyroxene rock, skarn-quartzite and garnet-bearing layers. A discordant body of very dark green rock is probably an ultramafic Ameralik dike. It is in turn cut by a deformed granitic dike of Qârusuk type. The Akilia lithologies have mafic segregation pegmatites of the type formed in basic rocks during granulite facies metamorphism.

Table 7. Analyses of Malene supracrustal basic and ultrabasic rocks from Sitdlisît nûat, Bjôrneføn, and Ivisârtoq.

	131501	152771	152772	207625
SiO <sub>2</sub>	51.47	47.02	43.04	46.49
TiO <sub>2</sub>	2.48	0.33	1.29	0.55
Al <sub>2</sub> O <sub>3</sub>	14.44	9.48	8.62	9.37
FeO	11.75	10.80	12.35	11.16
MnO	0.21	0.21	0.20	0.23
MgO	2.50	16.23	14.49	17.05
CaO	8.75	11.80	12.92	11.96
Na <sub>2</sub> O	4.5	1.45	1.70	2.03
K <sub>2</sub> O	0.89	0.07	0.20	0.02
P <sub>2</sub> O <sub>5</sub>	0.44	0.18	0.25	ND
LOI	0.37	0.90	2.80	—
Total	97.80	98.47	97.86	98.96
Rb	23	2	1	9
Cu	600	53	100	
Sr	419	66	140	37
Ba	730	7	13	
Zn	110	88	125	81
Y	30	9	17	9
Zr	189	16	67	28
Pb	19	2	—	
Nb	13	2	7	1
Cr	110	2449	2641	1765
Co	46	65	68	
Ni	87	500	607	556

131501: Amphibolite with possible relic pillow-lava structure, Sitdlisît nûat.

152771, 152772: Green tremolite-chlorite rock with possible relic pillow-lava structure, Sitdlisît nûat.

207625: Komatiitic metavolcanic rock from sequence of pillow-structured and associated homogeneous flow amphibolites, Ivisârtoq (Hall, 1980; Friend et al., 1981).

131501, 152771, 152772: Leeds University XRF analyses.

On the last point where the coast turns into the bay with the second stream there are clearly discordant Ameralik dike amphibolites that cut gneisses with spotty pegmatites of the type found elsewhere in rocks known to have been retrogressed from granulite facies. There are small enclaves of Akilia hornblende-clinopyroxene rock.

From here one can return to the hotel along the coast or by climbing up the northern branch of the stream and then either traversing obliquely back down to the coast or continuing up over a 600 m-high ridge and then down to the Nigsik valley.

The basic unit that crops out in the stream above Qíngua was mapped as Malene supracrustals, but we now think it more likely to be an unusually large unit of Akilia association. It contains thin layers of magnetite- and clinopyroxene-bearing quartzites, which are typical Akilia lithologies not observed in Malene basic units. It also contains mafic segregation pegmatites like those seen in the Akilia unit on the coast and several layers of massive amphibolite that may well be concordant Ameralik dikes. Pale grey, talc-bearing ultramafic rocks with grey, asbestiform amphibole are associated with the unit.

On the slope between the stream and the top of the 600 m ridge there is a thick basic unit with large ultramafic bodies that is mapped as Akilia association.

From the top of the ridge one descends into the Nigsik valley through the same unit of Amîtsoq gneisses as crops out on the coast traversed earlier in the day. Along the stream in the valley, Qôrqt granite and pegmatite sheets alternate with Amîtsoq gneisses containing rafts of various Akilia lithologies including quartz-magnetite ironstones, hornblende and other ultramafic and mafic rocks. They are cut by clearly discordant Ameralik dikes.

For those who return early to the hotel, there are pleasant and interesting walks along the coast to the west where there are good exposures of Qôrqt granite that, especially to the west, encloses rafts of Amîtsoq gneisses and ultramafic rocks, or up the stream behind the hotel, where the rocks are those mentioned in the last paragraph.

## EXCURSION 6

### QÔRQUT - NUUK

Localities for Excursion 6 are shown in Fig. 30.

#### Locality 6.1: Rockfall at Ujará

This locality shows partial melting of Amîtsoq gneisses and the production of group 1 granites. It is in the lower zone of the Qôrqt granite complex and consists of inhomogeneous, polyphase granite containing many enclaves of modified Amîtsoq gneiss.

At Ujarâ the whole process of partial melting may be demonstrated and some idea of the conditions under which this melting took place may be obtained. Given the mineral assemblages of the pegmatite-banded Amîtsoq gneisses and the granitic product, partial melting took place under a maximum of mid-amphibolite facies conditions. Enclaves of slightly modified Amîtsoq gneiss (mesosome) may be found progressively changed into a banded metatexite with granitic, hypidomorphic granular-textured felsic layers (leucosome) separated by biotite-rich layers (melanosome). A range of these textures and structures is shown in Figs. 12 and 13. With an increase in the volume of granitic material, fluid turbulence occurred and the metatexite became disrupted, resulting in the formation of inhomogeneous diatexite. This comprises leucocratic granite containing schlieren of biotite and enclaves of metatexite that were undergoing disaggregation.

At this locality there is good evidence for the formation of small batches of inhomogeneous granite, and hence an explanation for the polyphase nature of the complex. There was little mixing of the liquids that were produced partly because of the small volume of each batch, and partly because of thermal and viscosity contrasts. The inhomogeneity of the leucocratic granite is the result of disruption and incorporation of melanosome into the liquid. Disaggregation of the schlieren, or their smearing out to form biotite lamellae can also be seen, suggesting that much of the biotite in the granite could be derived

from the parent gneisses. Layering in the leucocratic granite has several origins. Most commonly it is an alternation of slightly different granitic lithologies, often separated by biotite lamellae. These may have been different batches of liquid that are contained within a biotite membrane and that have been attenuated by shear, or a biotite lamella may have been exploited as a line of weakness by an intrusive sheet.

The cliffs of the mountains to the north-northwest and on the opposite side of Ūmánap suvdlua show the intermediate zone of the Oôrqt granite complex, composed mainly of group 2 grey granites and enclaves of country rocks. The tops of the mountains are in the upper zone that is made up of group 3 composite granite sheets separating lozenge-shaped rafts of country rocks.

#### Locality 6.2: South-East Corner Of Storø

This locality is in the lower zone of the Qôrqt granite complex. Group 1 leucocratic granites contain enclaves of Amîtsoq gneisses and associated lithologies. A few enclaves have been carried into this part of the granite from parts of the complex where granite formation had taken place, while the majority are unmodified and therefore probably locally derived.

The enclaves at locality 6.1 are thought to have been brought in a short distance from the melting zone. To the north-east across the fjord, under Qáqarsuaq on the south side of the mouth of Qôrqt, Nûk gneisses (which contain enclaves of anorthositic rocks) show evidence of

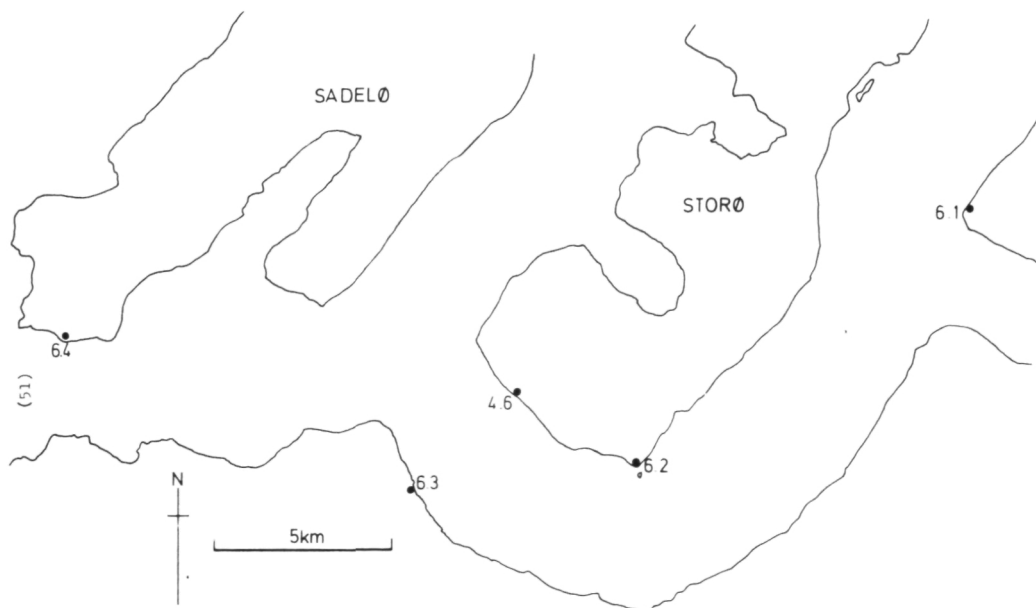


Fig. 30. Locality map for excursion 6.



arrested partial melting. Because of the extent of this outcrop it is considered that these rocks are probably *in situ* and thus are part of the melting zone.

The contact zone of the Qôrqt granite complex on the south side of the fjord is poorly exposed (by Greenland standards) because of lichen and algae that grow on the moist, north-facing rock faces. The exposures of Amîtsoq gneisses to the west are better and give a good impression of the density of Ameralik dike amphibolites in typical Amîtsoq gneisses. The thin unit of Malene amphibolite with bodies of ultramafic rocks is the same as the unit seen at the contact of the Qôrqt granite on the south coast of Storø.

#### Locality 6.3:

A thin, folded Ameralik dike that contains plagioclase clots is clearly discordant to layering in Amîtsoq gneisses on ice-polished slabs (careful, they are slippery!). It may be an apophysis of the thick, massive Ameralik dike exposed a little farther along the coast to the west.

#### Locality 6.4: South-West Coast Of Sadelø

The same unit of Amîtsoq gneisses strongly penetrated by Nûk gneisses as on the Nuuk peninsula around and east of the airport. The gneisses enclose many bodies of Ameralik dike amphibolite, some sub-continuous and others broken up, that are veined by gneiss and pegmatite. Several of the Ameralik dikes have clots of calcic plagioclase. The rocks are in the core of a synform and have a strong linear fabric with variable plunge.

On the steep coast to the west, many large, highly broken-up and migmatized Ameralik dikes can be seen as we sail past.

In these rocks it is very difficult to collect a sample of early Archean Amîtsoq gneiss that one can be sure does not contain any later material. We have generally avoided this type of geology in our collecting for isotopic and other studies.

Early Archean rocks in the south-eastern part of the region are commonly as strongly penetrated by younger material as those seen at Locality 6.4. In addition, however, they have suffered textural homogenization, like that seen in the gneisses at Kangimut sangmissoq, during recrystallization under granulite facies conditions. The resulting blebby textured gneisses, in which it is very difficult or impossible to distinguish the early Archean component from later material, remind V.R.M. of some of the outcrops he has seen in the Minnesota River Valley. Where, as is commonly the case, the texturally homogenized gneisses have been further deformed and intruded by later granitoids, recognition of an early Archean component becomes virtually impossible.

Table 8. Chronological sequence of events in the Godthåbsfjord - Ameralik - Færinghavn Region.

Age	Event
57 Ma.	Intrusion of "red dikes" around the mouth of Ameralik.
ca. 1150 Ma.	Mild thermal event shown by fission track ages.
1500-1600 Ma.	Metamorphism and metasomatism that caused partial recrystallization and is recorded in Rb/Sr mineral ages.
2000-1800 Ma.	Intrusion of basic dikes ( <i>MD dikes</i> ), faulting with retrogression under greenschist facies conditions.
ca. 2550 Ma.	Intrusion of post-tectonic granites and pegmatite sheets at ( <i>Qôrqt granite complex</i> ).
2700-2600 Ma.	Ductile deformation under amphibolite facies conditions. Formation of linear belts of intense deformation and elongate basins and domes. Intrusion of granitoid sheets (including the <i>Qârusuk dikes</i> ).
2800 Ma.	High-grade metamorphism that reached granulite facies conditions throughout the southeastern part of the region (Fig. 1), with amphibolite facies conditions in the outer Færinghaven-Godthåbsfjord tract.
2880-3100 Ma.	Intrusion of diorites, tonalites, granodiorites and minor trondhjemites, the protoliths of the <i>Nûk gneisses</i> , polyphase deformation.
2980 Ma.	High grade metamorphism which culminated in granulite facies conditions on Nordlandet.  Intrusion of anorthosite-leucogabbro-gabbro complexes into Malene supracrustal rocks.  Extrusion of subaqueous basic volcanic rocks with related sub-volcanic intrusions, deposition of sediments ( <i>Malene supracrustal rocks</i> ).  Intrusion of basic dike swarms ( <i>Ameralik dikes</i> ).
ca. 3600 Ma.	Metamorphism that reached granulite facies between Færinghaven and Qôrqt, and amphibolite facies in inner Godthåbsfjord. Intrusion of big-feldspar granodiorites and subordinate ferrodiorites ( <i>Amîtsoq iron-rich suite</i> ).
ca. 3750 Ma.	Intrusion (syntectonic?) of voluminous tonalites, the protoliths of the <i>Amîtsoq layered grey gneisses</i> . Intrusion of granite and pegmatite sheets, deformation and metamorphism.
ca. 3800 Ma.	Extrusion of basic and subordinate felsic volcanic rocks, deposition of chemical sediments and subordinate felsic and pelitic sediments, intrusion of gabbroic sheets ( <i>Akilia association</i> ). Correlated with the Isua supracrustal rocks.

## Acknowledgments

We wish to express our gratitude to the Geological Survey of Greenland for support both in and out of the field over many years (for 20 years in the case of V.R.M.). V.R.M. acknowledges support from the Danish National Scientific Research Council for field work in 1982 and 1984. A.P.N. acknowledges financial support in the period 1980–1985 from the Royal Society of London, the Danish National Scientific Research Council, the Carlsberg Foundation and the Memorial University of Newfoundland. C.R.L.F. acknowledges financial support from the Royal Society of London in 1982 and 1984, and the Research and Advanced Studies Committee of Oxford Polytechnic for various financial and logistic assistance in the period from 1976. We thank all of these institutions for supporting our research in the Gothåbsfjord region. This paper is published with permission of the Geological Survey of Greenland.

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